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# Master’s thesis

**under the speciality** 141 Electrical Energetics, Electrical Engineering and Electromechanics
**specialization** Electric Power Distribution Systems Engineering

**on the topic:** “Combined method of recovery of data on electric power consumption”

Completed by: Master student (2d year), group OE-81мн

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I declare that this Master's thesis does not include any borrowings from the works of other authors without corresponding references.
Student _____________
(Signature)

Kyiv, 2020

The master's thesis is performed on the subject: "Combined method of recovery of data on electric power consumption" with a specialization in 8.090603 "Electrotechnical systems of electric consumption". The scientific paper contains 5 sections, 105 pages, 61 figures, 13 tables and 59 information sources according to the list of references.

**Subject relevance**

When entering metering values on the level of consumption of resources there can be operation failures in counter devices. The difficulty of lost data recovery arises due to the diversity of consumption schedules. In order to solve this problem, it is necessary to develop a comprehensive approach to the process of recovery of unregistered values.

**Connection of the thesis with scientific programs, plans, and subjects**

The results of data recovery studies were used as recommendations for the recovery of lost accounting values for energy consumption at a chemical plant.

**Purpose and tasks of research**

The purpose of the thesis is to develop guidelines for the application of specific methods of information recovery. In the course of work the task is to compare existing methods of data recovery with different types of functions. As a parameter that determines the advantage of a particular method, the relative error is chosen.

The general task of the thesis is to show the advantages of local and global methods of data recovery when calculating electricity consumption compared with the methods used by power supply organizations.

**Object of research**

In this paper, samples of data formed on electricity and gas consumption, as well as ammonia production, serve as a research object.

**Scope of research**

The scope of research covers the interrelation of the parameters of consumption and production.

**Research methods**

The paper describes two approaches to the recovery of lost data. The first one involves using local methods for information recovery.

The second approach involves applying global methods.

In order to verify the reliability of the results of information recovery methods, data that did not contain gaps was used and the result was comparable due to the calculation of the relative error.

**Scientific novelty of the results**

In the process of solving the problem the following scientific results were obtained:

1) The combined method of lost data recovery allows us to get better results in comparison with the application of a particular method due to its adaptation to different types of functions.

2) The developed method can be used more conveniently for calculation of consumed electricity in comparison with existing ones. This is achieved by the fact that the method takes into account the nature of electricity consumption during the calculation period.

**Practical value of the results**

The developed method of signal processing covers a wide range of tasks. It can be used at enterprises that keep records of the consumption of electric energy, it can be used in calculations for electricity consumed by both enterprises and power supply organizations.

**Approbation of the thesis results**

On the subject of the scientific research, a scientific report was made at the XXX International Scientific and Technical Conference "Electronics and Nanotechnology"

**Publications**

**Keywords:** *method, data recovery, local, global, diagrams of electrical loads, simulation, statistical method, approximation, relative error.*

# TABLE OF CONTENTS

## LIST OF ABBREVIATIONS

ASCEA – Automated System of Commercial Electricity Accounting;

ASEA – Automated System of Electricity Accounting;

MICAP – Measuring and Information Complex of the Accounting Point;

DPS – Data Processing System

NIF – Natural Illumination Factor

RUEE – Rules for the Use of Electric Energy;

RIEGE – Rules for the Installation of Electricity-Generating Equipment;

UTS – Universal Time System;

PT – Potential Transformer;

CT – Current Transformer.

# INTRODUCTION

When entering metering values on the level of consumption of resources there can be operation failures in counter devices. In order to prevent data loss and reduce its negative consequences, it is necessary to find out the reasons for which they occur. The information stored in the counter devices is extremely vulnerable, and various factors can cause damage to it.

When accounting data are lost, there is a need to recover them. The difficulty of lost data recovery arises due to the diversity of consumption schedules. In order to solve this problem, it is necessary to develop a comprehensive approach to the process of recovery of unregistered values. The scientific paper proposes the use of a combined data recovery method that combines local and global recovery methods.

Nowadays, local and global data recovery methods are among the most widely used ways to recover lost information. The spread of these methods is concerned with the fact that, applying them, we can get the best result of data recovery. The proposed information recovery approach provides for optimization of the choice for solving the assigned problems.

As an assessment of the results obtained, the source data are compared with the data obtained by local and global recovery methods using the relative error. It also compares the economic result of data recovery compared to the methods used by power supply organizations.

The results of data recovery studies are proposed to be used as recommendations for the recovery of lost accounting values for energy consumption.

# 1 LOSS OF ACCOUNTING VALUES FOR ENERGY CONSUMPTION

## 1.1 Causes and frequency of information loss

One of the main tasks at industrial enterprises is to reduce information risks and ensure information security. With regard to the above mentioned, information risk determines a random event that negatively affects the enterprise information system and leads to software failures and economic damage. Information risk can be described as the possibility of a random event in the enterprise information system, which leads to a disruption of its functioning, a decrease in the quality of management information, as a result of which the enterprise incurs losses [1].

One of the causes of information risks in project management is the loss or misrepresentation of information. Loss of information may be complete or partial. In order to prevent data loss and reduce its negative consequences, it is necessary to find out the reasons for which they occur. The information stored in the counter devices is extremely vulnerable, and various factors can cause damage to it.

Figure 1.1 shows the causes as a result of which information may be lost.

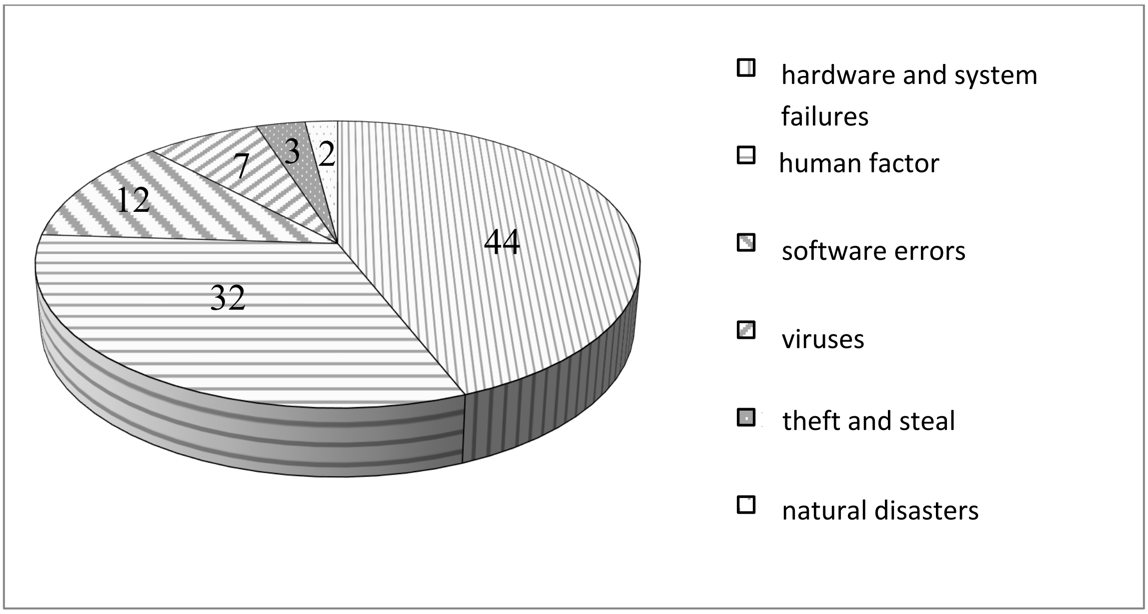


Figure 1.1 – Causes of information loss

Let us consider in more detail the causes as a result of which information may be lost:

1) *Hardware and system failures*. The main cause of data corruption, of course, is hardware failure - according to statistics, at least 44% of data loss cases are associated with it. Hardware failure occurs for various reasons: power failure, damage to the drive, failure of the drive control circuit, failure of its electromechanical part. In case of malfunctioning of the hardware, error messages appear: for example, about its unavailability. In addition, previously accessible data disappears.

2) *Human factor*. Contrary to popular belief, user error is the second leading cause of data loss (about 32%). If data accessible on a normally functioning device disappear, then in most cases the responsibility for this lies with the user. For example, due to the user's lack of experience and knowledge in working with this counter device.

We can insure against the consequences of user errors by regularly making backup copies of the necessary data. Furthermore, it is not allowed to install new devices, repair or configure the system without relevant experience.

3) *Software errors.* Software defects cause data loss in approximately 14% of cases. Software defects are the result of developer errors and incomplete testing of software at the debugging and implementation stage. Normally operating settings on one counter may behave completely unpredictably on another. As a rule, software defects are caused by an error message, which refers to the loss of data or damage to it (most often problems arise immediately after installing new software). In addition to data loss messages, memory error warnings may appear. In such a situation, we must immediately find the software, that causes damage to the data, and update its version or fix the error using a corrective software, or uninstall the defective software.

4) *Viruses*. It is believed that viruses are the main cause of information loss, but they account for only about 7% of all data corruption. However, this share has

recently increased as the popularity of information exchange via wireless networks such as GSM and Wi-Fi grows. The number of viruses is measured in tens of thousands, and their new varieties appear every day. But the capabilities of most viruses as data "destroyers" are rather limited.

5) *Theft and steal.* Counter devices are easy enough to dismantle and sell in the market, so they can become the target of thieves. Of course, with the loss of the counter device all the information about the accounting data that were stored on it disappears. Regular backup and storage of copies in a safe place pursues, primarily, the following purpose: to save data even when storage media disappear.

6) *Natural disasters.* Fire, flood, earthquake, lightning strike – these natural disasters account for about 3% of data loss cases. Since in the described situations it is hardly possible to prevent the destruction (at the best case – damage) of the counter device, a reliable way to protect data from such disasters is to store backup copies of data in a safe place.

## 1.2 Requirements for ASCEA counter devices at enterprises

The construction and implementation of automated power control systems for industrial facilities is becoming one of the government's policies in the field of energy conservation. All electrical energy consumed during the extraction, processing, transportation, storage is subject to mandatory accounting. A special feature is the complex solution of tasks related to automation of electricity accounting at industrial and public sector facilities [4].

One of the tasks solved in the process of constructing an automated control system for industrial facilities is the automation of electricity accounting. The emergence of this task was due to the requirement to improve the efficiency of processing the registered information on electricity [5].

In order to record the amount of electricity consumed at industrial facilities, data acquisition devices are used. Electricity registrations are checked for completeness and accuracy by calculating electricity balances by connection groups and the power plant as a whole for a certain period of time.

In the case of the absence or unreliability of the amounts of electricity consumed registered by the data acquisition device, it can be recovered on the basis of alternative options. As alternative options, operational documents on the maintenance of the mode, market subjects, automated systems for monitoring the parameters of power facilities and remote control operational-measuring complexes can be used. To account for electricity, technical means are used, the characteristics of which are taken into account when calculating the permissible unbalance.

Automated system for commercial electricity accounting (ASCEA) is a type of automated information-measuring system and is a set of functionally integrated information-measuring complexes, systems and devices [6].

ASCEA can include one or several information-measuring complexes of accounting points, an information-computing complex, a universal time system and an information-computing complex of electricity-generating equipment. The composition of a typical ASCEA is shown in Figure 1.2.

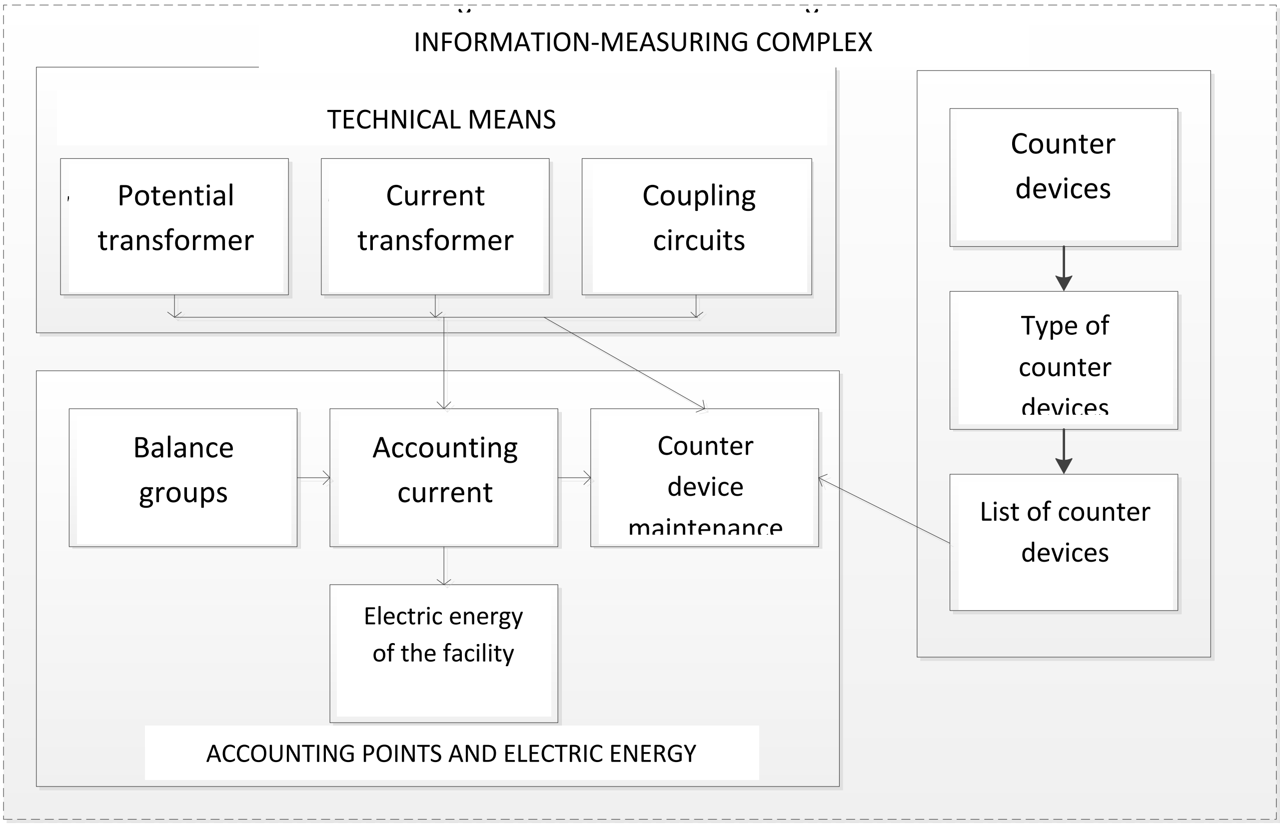


Figure 1.2 - Structural diagram of the information-measuring complex of electricity accounting

The main purpose of the ASCEA implementation is the measurement of the volume (amount) of electricity consumed, which allows us to determine the values of accounting indicators used in the calculations for the distribution of electricity to energy consumption facilities.

In order to achieve these goals, ASCEA should provide:

- measurements of 30-minute increments of active electricity and integrated reactive power;
- periodic and (or) on-request automatic collection in a single astronomical time of measured data on the increment of electricity with a given accounting resolution;
- data on measured values and service information should be stored in a specialized database with enhanced security against information loss and unauthorized access;

- transmission of commercial and control information to the dispatcher of the power system;
- on request access to commercial and service information from the dispatcher of the power system at the level of the information-computing complex of the electricity-generating equipment and, if possible, the information-measuring complex of the accounting point;
- access to technical information from the dispatcher of the power system at the level of the information-computing complex;
- diagnostics, monitoring and collected statistics on errors in the functioning of technical means of ASCEA;
- registration, monitoring of events in ASCEA at the level of information-computing complex (events of counter devices, routine actions of personnel, violations in the system of information protection, failures, etc.);
- configuration and setting of ASCEA parameters [7].

Thus, ASCEA should be created as a hierarchical integrated automated system, which should include (see Figure 1.2):

- information-measuring complexes for electricity accounting points in the supply section of the wholesale market entity;
- information-computing complexes for electricity-generating equipment of the wholesale market entity;
- information-computing complex;
- universal time system.

Consider the requirements for current and potential transformers, which are installed in the ASCEA system.

1. In case of new construction or reconstruction of electricity-generating equipment of the market subject to which the network elements included in the supply section are connected, current transformers of accuracy class not lower than 0.5 S should be installed on these elements, potential transformers of accuracy class not lower than 0.5.

2. Measuring transformers should be installed at electricity accounting (supply) points.
3. A control of the integrity of the potential transformer circuit should be provided, in the case of using a potential transformer only for commercial accounting purposes.
4. For commercial measurements in networks with a solidly earthed neutral, current transformers should be installed in three phases, to which three-phase three-element counter devices should be connected.
5. The use of intermediate current transformers is not allowed.
6. It is not allowed to overload the measuring transformers in all operational modes.
7. The measuring transformers must comply with the Rules for the Installation of Electricity-Generating Equipment (RIEGE) for voltage class, electrodynamic and thermal resistance, climatic modification.
8. Displays of measuring transformers used in measuring circuits must be protected from unauthorized access.

The following requirements are set for the ASCEA complex:

1. Requirements for computing equipment. The computing equipment must meet the requirements of international standards ISO 9000 - 9001. Technical means should be placed in compliance with the requirements contained in the technical, including operational, documentation for them, and with a convenient location for their operation and maintenance.
2. Requirements for the ASCEA software. The software must have a convenient user interface (including auxiliary and service functions) and it must certified by the State Committee of Ukraine for Technical Regulation and Consumer Policy.
3. Requirements for the information model:

- the description and characteristics of the technical means of measuring complexes used for electricity registration (potential and current transformers, coupling circuits, counter devices);
- the list and characteristics of the accounting points (under the accounting point it is understood the place of registration of electricity indicating the type and direction of electricity);
- the amount of electricity registered at the accounting points.

The proposed model will allow us to provide automated accounting of supply and flow of electricity and solve the following tasks:

- accounting and maintenance of technical means of measuring complexes;
- formation of the passport-protocol of the measuring complex;
- control of the authenticity of the amount of registered electricity;
- correction of the amount of registered information;
- formation of the statement of registered electricity correction;
- calculation of the balance at the facility;
- formation of the statement of electricity balance at the facility (power plant);
- formation of samples of information on the flow of electricity for outside organizations.

The above information is stored in the database of the information model and it is available on a round-the-clock basis.

## 2 METHODS OF DATA RECOVERY AND THEIR SCOPE OF USE

In practice, statistical analysis is limited to analyzing not only the general series as a whole, but only a few selective observations. The analyzed sample should meet the criteria of quality and completeness. In reality, one has to deal with a situation where some of the properties of one or several objects are missing - the presence of data with gaps, which significantly complicates mathematical processing. In this case, the displacement of the main statistical characteristics, such as the mathematical expectation or dispersion, increases in direct proportion to the number of gaps. Currently, in mathematical statistics there are several ways to solve the problem of incomplete data [8]:

- the exclusion of incomplete objects from the input sample. This approach can be characterized as incorrect, since incomplete data carries the new information required for research, and therefore it is important to include them in the analysis;
- the application of specially developed mathematical methods for analyzing the incompleteness of data, such as the method of weighing or the method of maximum likelihood and EM-algorithm (while significantly increasing the complexity of the analysis) [9];
- the recovery of gaps (the most common methods of filling by the mean and regression). In most cases, this approach is considered to be the most effective and convenient solution to the problem.

The reasons for the occurrence of gaps in data can be quite different, so knowledge of the mechanism leading to the lack of values is key in choosing the methods of analysis and interpretation of the results. The mechanism of generating gaps gives an understanding of the importance of lost information.

Correction is an example of a situation where the mechanism of generating gaps can be unmanaged, but known to a statistician. Input data is the time of occurrence of some event. For some sample objects, the time of the event is corrected, because the event did not have time to occur before the end of the experiment. At a known correction time, we have partial information on: the time of occurrence of the event, which was not observed more than the correction time. Such information should be taken into account in the analysis in order to avoid displacements.

It is commonly when the mechanism of generating gaps is clearly not included in the model - it means that this mechanism is ignored. However, the mechanism of the gaps can be entered into the statistical model, including the distribution of presence indicators - some function $I = \{0,1\}$, which takes value 1 if there is an attribute and 0 - for the gap. In the general case, the mechanism of gaps can not be neglected.

There are many ways to fill the gaps after the data collection stage: filling with the average value, proportional placement of observations with missing data according to the available grades of the scale, calculation of the possible value using a regression model, etc. [10]. Filling the gaps allows not only to obtain additional information (specified values), but also to preserve the information that is already available, often very important and obtained with significant efforts, by maintaining observations with gaps.

In addition to the obvious advantages of data recovery, the solution to the problem of missing information has several disadvantages that can not be ignored:

1. The use of existing comprehensive data for prediction of gaps distorts the structure of the resulting data (after data recovery).
2. The artificial substitution of gaps introduces a certain proportion of artificial data to the array, which in turn leads to a shift in the significance of the results obtained on their basis [9].

When choosing a specific method for restoring missed values, it is necessary to take into account: the algorithms for filling the gaps are not universal and the possibility of using one or another method of filling the gaps depends on the method of data analysis, which is planned to be used in the future.

The most popular of the existing data recovery methods are presented in the most complete and detailed classification by R. Little, and shown on the following scheme (see Figure 2.1).

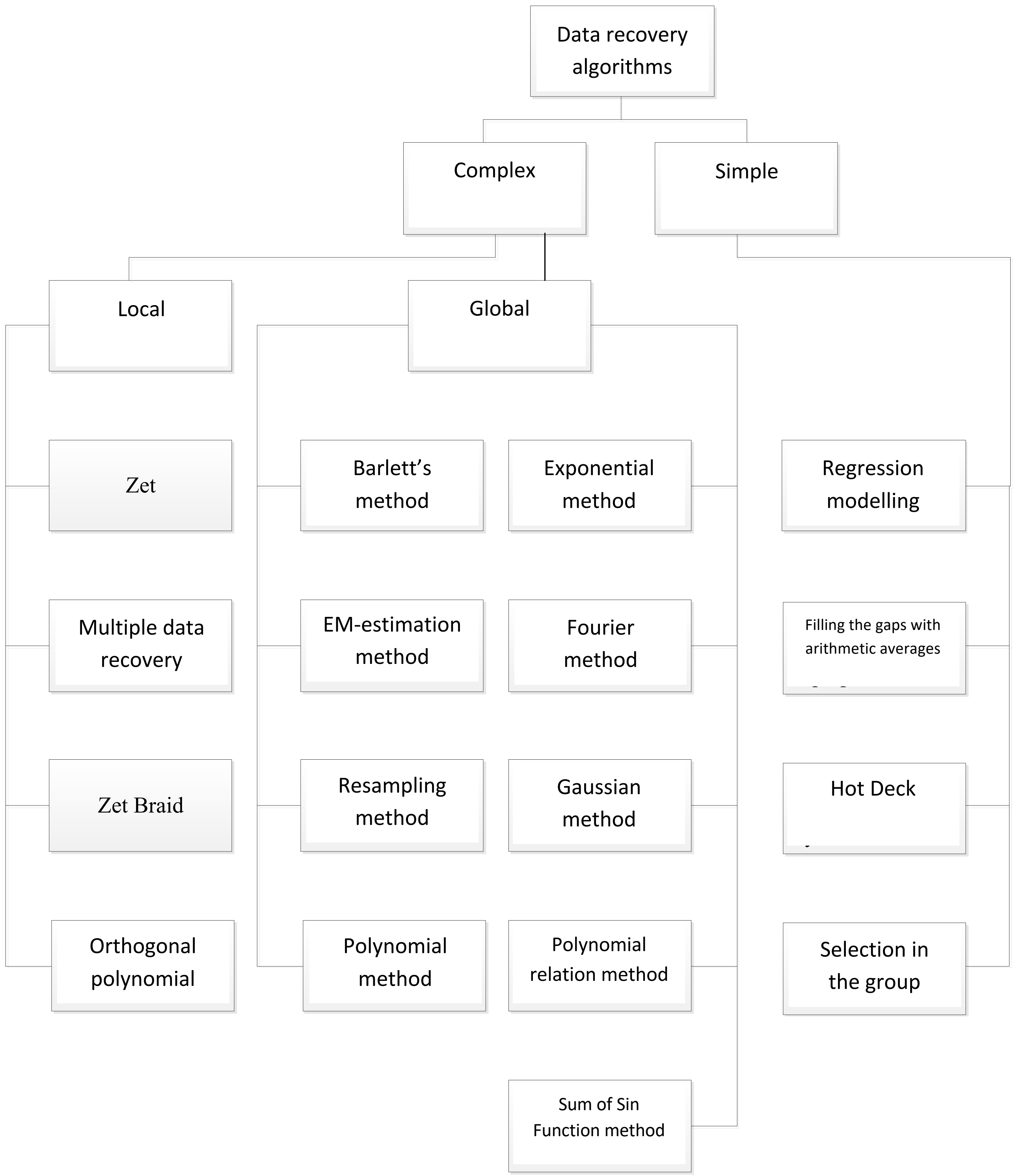


Figure 2.1 - Classification of data recovery algorithms

Let us describe the groups of methods that can be used to recover data:

Simple algorithms - non-iterative algorithms, based on simple arithmetic operations, distances between objects, regression modeling. These include filling the gaps with arithmetic averages, regression modeling of gaps, the HotDeck method and selection in the group.

Complex algorithms - iterative algorithms, which involve the optimization of some functional, reflecting the accuracy of the calculation, and substitutes for the place of the missing value. They can be divided into global and local.

Global algorithms - in estimating (forecasting) each missing value all objects of this sample are taken: the Barlett's method, EM-estimation and Resampling.

Local algorithms - in estimating (forecasting) each missing value, full observations are used that are within the limits of the object being studied. This group includes the ZET and ZET Braid algorithms.

## 2.1 Statistical ("simple") methods

Let us consider the listed methods for recovering data included in this group.

*Filling with the mean and selection within the groups.* The method of filling with the mean values replaces all the missing values with the mean of this attribute, calculated on the basis of available data.

In this sample, the data is divided into groups according to a certain attribute; within each group, only the value present in it is used to fill in the gaps [8].

*Hot Deck method*. The method is used in one stage studies and is a substitution instead of the missing value of this variable of the closest object with complete information. Moreover, the selection can be carried out both from the whole set of complete observations, and from its certain subgroup – the cluster to which the target object belongs.

In order to fill the gap, the value of this characteristic of the object closest to the target (the distance to which from the target object is less than to all other objects) is used.

The type of the distance function to determine the closest to the target (with the gap) observation is selected based on the type of data used, the researcher's views on the nature of the relation between variables and the tasks of each specific study [12].

*Method of regression modeling of gaps*. In most cases, the removal using regression models is carried out in two stages:

1. In the first stage, on the basis of a set of complete observations, a regression model is rebuilt and coefficients are estimated in the equation, where the target variable serves as a dependent variable – the missing values.
2. Then, using the equation obtained in the previous stage, into which the values of the independent variable predictors are substituted, for each target object, missing values are calculated for the dependent target variable. In the case of interval and absolute variables, a specific value is calculated, and for serial and nominal variables, with some probability, a category is assumed to be assigned to the object.

The choice of a regression model for calculating the missing values of a variable is determined by the level of measurement of the target dependent variable (the value of which needs to be recovered) and independent variables, according to which the missing values will be provided [10].

## 2.2 Local and global methods

In contrast to the statistical (probabilistic) approach, which operates with mean values or the probability of finding the desired value in a certain range of values, the dynamic (deterministic) modeling approach assumes an exact specification of the state of the object and a unique prediction of its future behavior.

### 2.2.1 Global methods

*Barlett's method.* The method consists of two stages: substitution instead of missing initial values in the first stage, and carrying out of the covariance analysis of the target variable and the dichotomous indicator of completeness of observation of the target variable in the second stage. The observation completeness indicator is always 0, except for one case where the value of the target variable is missing, then it takes the value 1 [8].

*Resampling method*. In this algorithm, the series containing the missing data are replaced with randomly selected series from the matrix of complete observations. Then a regression equation is constructed to predict the missing value.

The procedure for constructing regression modeling is repeated several times. After a certain number of repetitions, the value of the obtained regression coefficients is averaged and a final solution is obtained, which gives the maximum accuracy of the prediction of the missing value [8].

*The EM-estimation method.* The expectation maximization method (EM – expectation maximization), in some sources – EM-estimation, allows not only to recover missing values using a two-stage iterative algorithm, but also to estimate mean values, covariance and correlation matrices for quantitative variables.

The EM-algorithm is an iterative procedure designed to solve the optimization problems of some functional through the analytic search for the extremum of the target function.

The given algorithm is implemented in 2 stages. First letters of names that form the general abbreviation of the algorithm:

At the first stage, so-called the E-stage (expectation), based on the set of totally or partially complete observations available, the conditional expected values of the target variable for each incomplete observation are calculated. After receiving an array of complete observations, the main statistical parameters are estimated: average trend and spread, indicators of mutual correlation and covariance of variables.

In the case of working with incomplete data at the E-stage, the conditional expectation function of the logarithm of the full likelihood function is determined for a known sense of the target variable. After determining the type of this function, the second stage of the algorithm begins – the M-stage.

At the second stage, so-called the M-stage (maximization), the algorithm task is to maximize the degree of mutual correspondence between the expected and substitution data, as well as the correspondence of the structure of the remote data to the structure of the complete observations data [13].

### 2.2.2 Local methods

In contrast to global models aimed at describing the dynamics in the whole space, local models describe the behavior of the system in parts.

*ZET algorithm.* The essence of the algorithm lies in the selection for each missing recovery value not from the entire sample of complete observations, but from some part of it – the component matrix. It consists of component lines and columns. The component of some line or object is a value inversely proportional to the distance to the target line (incomplete observation with a gap) in space, the axes of which are defined by variables – the considered characteristics of objects.

Then, according to the data of the component matrix, the functional dependence of the predicted value on the corresponding value in the component matrix is built, on the basis of which the gap value is predicted [14].

*ZET Braid algorithm.* The main difference and at the same time the advantage of the ZET Braid algorithm (braiding) from the ZET algorithm is the presence of an apparatus for determining the dimension of the component matrix objectively.

In the process of the algorithm, sequential selection of component lines and component columns occurs. Each time a new line or column is selected, a new component matrix is formed. According to a given criterion, its effectiveness in predicting gaps is determined [11].

*Multiple data recovery.* The method was developed by Donald Rubin in the 1970s of the 20th century. From the point of view of Rubin, the attribution to each gap of several potential values is intended to reflect the degree of uncertainty from which the deletion is carried out. Now this method is the most promising and is implemented in specialized software, unfortunately, to a greater extent in commercial [15].

The technique of multiple data recovery involves the substitution of several values at once in the place of each of the gaps. The significant spread of these values indicates the uncertainty of the model and does not allow an unambiguous conclusion about their type and cause of occurrence.

The data with each set of filled gaps are stored in separate arrays, each of which is then analyzed as created from complete observations [9].

# 3 ACCURACY OF INFORMATION RECOVERY

## 3.1 Random data removal

Preliminary processing of the obtained data involves identifying random values and smoothing the series. The reasons for the appearance of random data may be technical errors in the collection, processing and transmission of information. These errors are called errors of the first kind, they can be detected and eliminated, or measures can be taken to prevent them. In addition, random data may occur due to the influence of factors that have an objective character, but they act sporadically. Such errors are called errors of the second kind; they cannot be eliminated, but can be excluded from consideration by replacing the random value with the arithmetic average of two adjacent series [21].

To detect random values of the series, the Irwin criterion is used, according to which the point $Y_t$ is considered random, which differs from the previous point $Y_{t-1}$ by the value of the larger standard deviation:

$$\lambda_i = \frac{|Y_t - Y_{t-1}|}{\sigma},$$

where $\lambda_i$ is the Irwin criterion;

$\sigma$ is the standard deviation.

A point is considered random if $\lambda_i > \lambda_{tab}$. Table values $\lambda_{tab}$ (table 3.1) decrease with increasing the series length.

Table 3.1 – The value $\lambda_{tab}$ depending on the size of the series

| $n$ | 10 | 20 | 30 | 50 | 100 |
|---|---|---|---|---|---|
| $\lambda_{tab}$ | 1.5 | 1.3 | 1.2 | 1.1 | 1.0 |

Smoothing the time series allows us to filter out small random fluctuations and to identify the main trend of changes in the studied quantity. In mechanical smoothing, the alignment of individual series is performed using the values of adjacent series. The following methods are used for smoothing:

Simple (arithmetic mean) variable of the mean:

$$Y_t = \frac{\sum_{i=t-p}^{t+p} Y_i}{2p+1};\ p < t < n-p.$$

Smoothed value $Y_t$ is an arithmetic mean of $2p + 1$ adjacent points. 5 points smoothing is the most commonly used.

$$Y_t = \frac{Y_{t-2} + Y_{t-1} + Y_t + Y_{t+1} + Y_{t+2}}{5}.$$

Weighted (weighted average) variable of the mean:

$$Y_t = \frac{\sum_{i=t-p}^{t+p} \rho_i Y_i}{\sum_{i=t-p}^{t+p} \rho_i};\ p < t < n-p.$$

In this method, each of the points is included in the total sum with the weighting factor $\rho_i$. For 5 points smoothing, weighting factors (-3, 12, 17, 12, -3) are used. Weighting factors (-2, 3, 6, 7, 6, 3, -2) or (5, -30, 75, 131, 75, -30, 5) are used for 7 points smoothing.

Chronological average:

$$Y_t = \frac{\frac{Y_{t-T/2}}{2} + \sum_{i=t-T/2+1}^{t+T/2+1} Y_i + \frac{Y_{t+T/2}}{2}}{T};\ \frac{T}{2} < t < n - \frac{T}{2}.$$

The above formula is used for momentary time series. Usually, the smoothing period is equal to the year, i.e., $T = 4$ quarters or $T = 12$ months [21].

Exponential smoothing. In this method, all previous points are used to smooth the current point, with the weighting values decreasing exponentially as it moves away from the current point. The exponential smoothing formula can be written as an expression in which the current point depends on all previous points:

$$Y_t = \frac{\sum_{i=1}^{t} \rho_i Y_i}{\sum_{i=1}^{t} \rho_i}.$$

But in this form, it is inconvenient to use, since each point requires its own set of weighting factors. Using recurrence relations, we obtain an expression for the current smoothed point in the form of a function from the current non-smoothed and previously smoothed point:

$$Y_t = \alpha Y_t + (1-\alpha) Y_{t-1};\ 0 < \alpha < 1,$$

where α is the smoothing parameter.

The fictitious initial value of the smoothed series is taken equal to the first point or the arithmetic mean of the first three points:

$$Y_t = Y_1 \text{ or } Y_t = (Y_1 + Y_2 + Y_3)/3.$$

When smoothing the time series by (2$p$ + 1) adjacent points $p$ at the beginning and at the end of the series, they are not smoothed. These points should either be omitted from consideration, or special smoothing formulas should be used for extreme points. In particular, in the case of three points smoothing, you can use the following formulas:

$$Y_t = (5Y_1 + 2Y_2 - Y_3)/6;\ Y_n = (5Y_n + 2Y_{n-1} - Y_{n-2})/6.$$

With exponential smoothing, neither the initial nor the end points are lost [22].

## 3.2 Analysis of the forms of energy consumption schedules

### 3.2.1 Check for gaps of the I kind

Let us assume that $y = f(x)$ and the argument $x$ varies from the value $x = x_1$ to the value $x = x_2$. The difference between the value of the argument is called argument increment and denoted as $\Delta x$.

Thus, $\Delta x = x_2 - x_1$.

where $x = x_1$, we have $y_1 = f(x_1)$, and where $x = x_2$, we have $y_2 = f(x_2)$. The difference of the function caused by the change of the argument is called function increment and denoted as $\Delta y$.

Thus, $\Delta y = y_2 - y_1 = f(x_1 + \Delta x) - f(x_1)$.

To understand the gaps of the first kind let us consider continuous functions. There are two definitions of continuity of a function at a point that is often used.

1. If an infinitesimal increment of the argument $\Delta x$ at the point $x = x_0$ corresponds to an infinitesimal increment of the function $\Delta y$ defined at the point $x_0$ and in its neighborhood, the function $y = f(x)$ is called continuous when $x = x_0$ or at the point $x_0$. From this definition it follows that in order to study the continuity of a function at the point $x = x_0$ it is sufficient that when $\Delta x \to 0$ $\Delta y \to 0$.
2. The function $y = f(x)$ is called continuous when $x = x_0$, if:
   1) $f(x)$ exists when $x = x_0$ and in some neighborhood of the point $x_0$;
   2) there is a finite boundary $\lim\limits_{x \to x_0} f(x)$;
   3) $\lim\limits_{x \to x_0} f(x) = f(x_0)$ regardless of the way $x$ to $x_0$, i.e. $\lim\limits_{x \to x_0 - 0} f(x) = \lim\limits_{x \to x_0 + 0} f(x) = f(x_0)$.

The last condition can be written as follows: $\lim\limits_{x \to x_0} f(x) = f\left[\lim\limits_{x \to x_0} x\right] = f(x_0)$.

This attribute specified below will be used for the classification of gap points.

3. If the function is continuous at each point of some interval $(a, b)$, then it is called continuous on the interval $(a, b)$. If the function is defined for $x = a$ and $\lim\limits_{x \to a+0} f(x) = f(a)$, then $f(x)$ is continuous at the point $a$ from the right. If $f(a)$ is defined for $x = b$ and $\lim\limits_{x \to b-0} f(x) = f(b)$, then $f(x)$ is continuous at the point $x = b$ from the left.

If $f(x)$ is continuous at each point of the interval $(a, b)$ and is continuous at the ends of the interval, respectively, from the left and from the right, then the function $f(x)$ is called continuous on the segment $[a, b]$.

If for some $x = x_1$, any of the conditions of continuity of the second definition is not satisfied, then the function at this point has a gap, and the point $x_1$ is called the gap point of the function. The concept of continuity and gap of the function can be clearly shown on the graph of the function (see Figure 3.1).

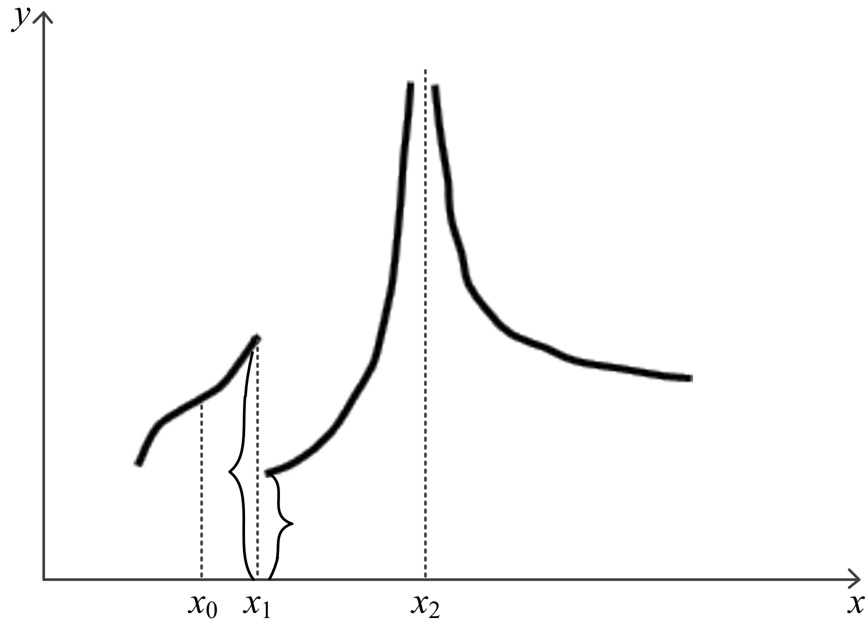


Figure 3.1 – Examples of function gaps

In the neighborhood of point $x_0$, the graph has the form of a continuous line. With any direction $x \to x_0$ $f(x) \to f(x_0)$. At the points $x_1$ and $x_2$, another case appears. When $x$ approaches $x_1$ from the left of $f(x) \to a$, and when $x \to x_2$, from the right of $f(x) \to b$, i.e. $\lim\limits_{x \to x_1} f(x)$ depends on the way of direction $x$ to $x_1$. At the point $x_2$, the condition of continuity of the function is also not satisfied because $\lim\limits_{x \to x_2} f(x) = \infty$, i.e., there is no finite boundary. The graph of the function shown in Figure 3.1 has gaps at the points $x_1$ and $x_2$.

The gaps of functions can be recoverable and irrecoverable:

1) if the function $f(x)$ is not defined at the point $x$, or is defined, but there is a relation:

$$\lim_{x \to x_1 - 0} f(x) = \lim_{x \to x_1 + 0} f(x) \neq f(x_1),$$

then the gap at the point $x_1$ is called recoverable. In this case, the function can be defined or its value can be changed at the point $x$ so that the equalities are valid:

$$\lim_{x \to x_1 - 0} f(x) = \lim_{x \to x_1 + 0} f(x) = f(x_1);$$

2) irrecoverable gaps are divided into gaps of the first and second kind:

a) if one-sided boundaries of the function $\lim\limits_{x \to x_1 - 0} f(x)$ and $\lim\limits_{x \to x_1 + 0} f(x)$ exist, and they are finite, but not equal to each other, then $x_1$ is called the gap point of the first kind, and the difference $\lim\limits_{x \to x_1 + 0} f(x) - \lim\limits_{x \to x_1 - 0} f(x)$ is called a function jump;

b) if at least one of the one-sided boundaries does not exist or equals to $\infty$, then the gap at this point is called a gap of the second kind.

In Figure 3.1, the function has a gap of the first kind at the point $x_1$, its jump is $(b - a)$, and at the point $x_2$, the function has a gap of the second kind.

### 3.2.2 Establishing data dispersion

The quality of each measurement should be evaluated within the concept of uncertainty. In accordance with this concept, the purpose of measurement is a reliable estimate of the parameters of the probability distribution, which characterize the measured value. Under these parameters, the mean value and the standard deviation are often taken into account.

Given the above measurement uncertainty means inaccurate measurement results. For a numerical evaluation of measurement inaccuracy, two basic questions should be answered:

a) to what specific limits around the measurement result can be the true value of the measured value;

b) with what probability the value falls within these limits.

The questions can be answered, based on the theory of probability and mathematical statistics. In this case both the measurement result and the measured value are considered as random variables. The random variable can be characterized as a set of measurement results, and their probabilistic distribution. This distribution makes it possible to estimate the dispersion of a random variable – an interval in which the value of a random variable can fall with one probability or another. The measurement uncertainty is a parameter that characterizes the dispersion of the measurement result probabilistic distribution. According to the theory of probability, distribution is determined by dispersion. An optional square root of the dispersion is called the standard deviation. The standard deviation, multiple to standard deviation, or half-width of the confidence interval (defined with a known probability), is usually the parameters that characterize the spread of the measurement result (and the measured value) and express the uncertainty of the measurement. The value (or range of values) of these parameters can be quantified using statistical methods. The estimate of the standard deviation of the random variable, found on the basis of the sample, is called the empirical standard deviation. In the measurement practice, the experimental standard deviation is used – the empirical standard deviation found by the set of measurements. The experimental standard deviation may be a specific numerical estimate of the measurement uncertainty.

In experiments, a pair of value $x$ and $y$, where the second value is the function of the first one, is often measured: $y = f(x)$. A good illustration of the interdependence of these values is shown in the graph (see Figure 3.2). In the general case, the graph represents a smooth curve without breakage. To get the presented curve, first of all, we must indicate the confidence intervals of the experimental points using straight lines, parallel to the axes of the graph. Then, through these areas, a smooth curve is made that would pass closest to the experimental points and simultaneously would pass through all confidence intervals.

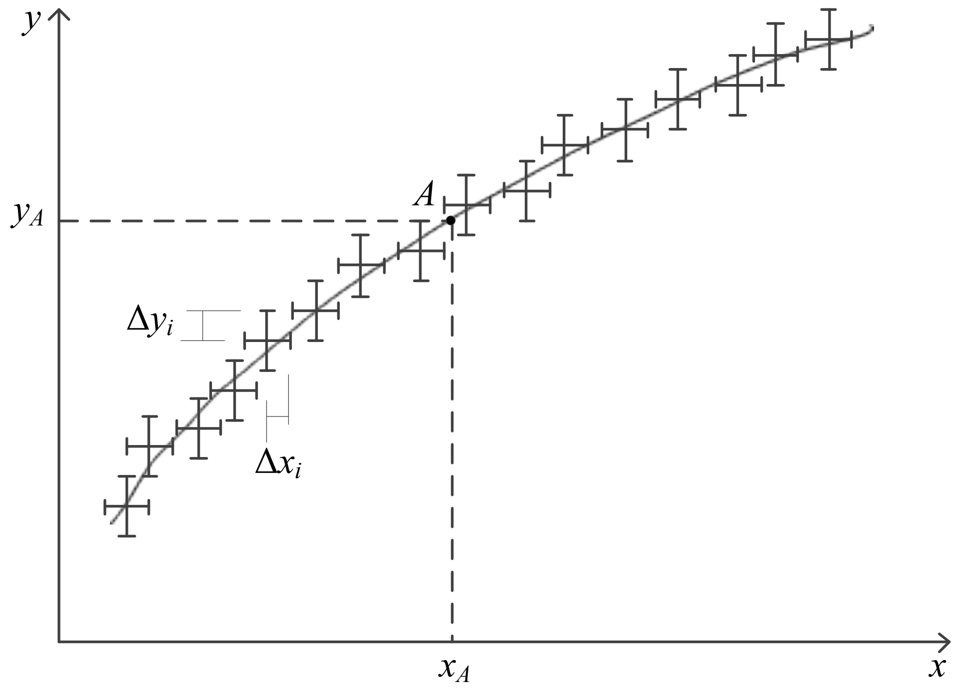


Figure 3.2 – Graph of dependence $y = f(x)$

In order to find the uncertainty of the ordinate of some point A on the curve presented in Figure 3.2, we should fix its abscissa (for example, $x_A$) and measure in the direction of the $y$-axis the deviation of $n$ experimental points (symmetrically located on the graph near the point $A$) from the smoothing curve, ($y_i$ - $y_i'$), $i$=1, 2, ..., $n$. $y_i$ is the ordinate of the experimental point corresponding to the abscissa $x_i$, and $y_i'$ is the ordinate of the corresponding point on the smoothed curve. The uncertainty of the fixed abscissa $x_A$ is considered to be zero; the extended uncertainty of the $A$-type for the ordinate is calculated by the formula (assuming the normal distribution of the differences ($y_i$ - $y_i'$)):

$$U_A(y_A) = t_{n-2,\beta}\sqrt{\frac{\sum_{i=1}^{n}(y_i - y'_i)^2}{n(n-2)}}.$$

A more precise, but at the same time more labor-consuming method of finding the smoothed curve is the method of least squares. Using this method, a smoothed curve is found for which the sum of squared deviations from experimental points is minimal.

Suppose that between the values of $x_i$ and $y_i$ there is a linear dependence:

$$y_i = Ax_i + B.$$

The slope $A$ and the constant term $B$ of the line are found by the formulas:

$$A = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sum_{i=1}^{n}(x_i - \overline{x})^2};$$

$$B = \overline{y} - A\overline{x},$$

where $\overline{x}$ and $\overline{y}$ – arithmetic mean values for $x_i$ and $y_i$.

### 3.2.3 Detection of sharp peaks or dips in function

One of the peculiarities of the power industry of Ukraine is the presence of a significant unevenness of the electrical load diagram. According to the Ministry of Energy and Coal Industry of Ukraine, the night excess capacity in Ukraine is more than 1100 MW and it tends to increase. One of the ways to use excess capacity and smooth the daily schedule of energy consumption is the use of energy-intensive industrial enterprises and the accumulation of excess energy at night. For this purpose, pumped storage units are used, as well as the generation of thermal energy with its subsequent use in the daytime. However, both of these types of accumulation are characterized by significant thermal and hydraulic losses, reaching 35% or more [24].

Typical daily diagram of electric load, reflecting the daily rhythms of life of society, common for many power systems, is shown in Figure 3.3. Based on the given diagram, there are three time zones: zone of minimum load (night hours or night breakdown) with power not more than $P_{\min}$ , zone of medium or intermediate load with power $P_{\mathrm{IL}}$ in the range of $P_{\min} \le P_{\mathrm{IL}} \le P_{\max}$ and zone of maximum or peak load with power not more than $P_{\max}$.

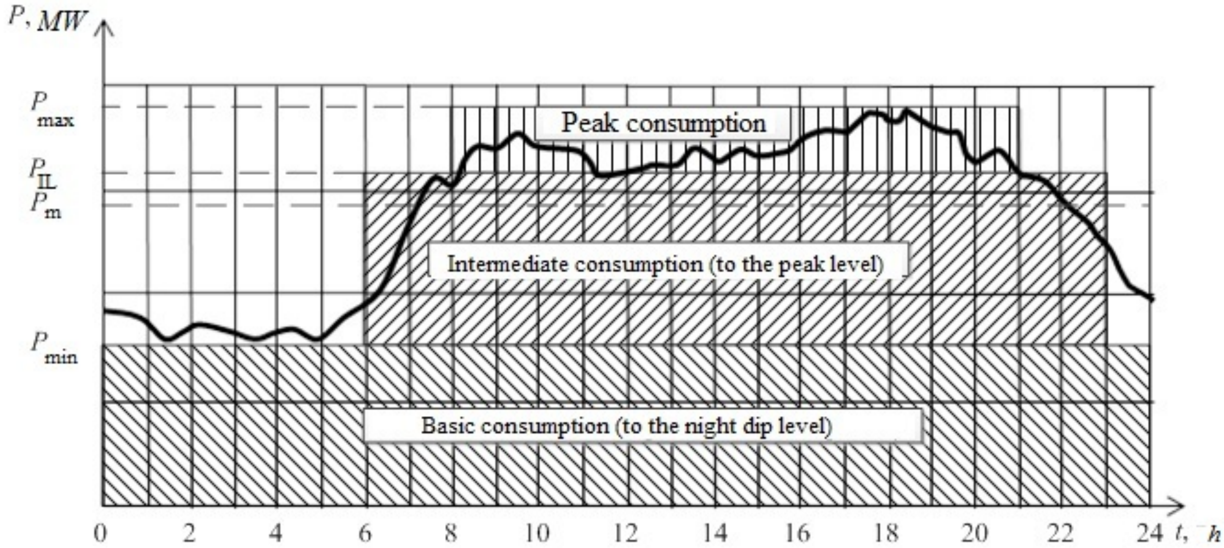

Figure 3.3 – Typical daily load diagram of the power system

The intermediate zone is characterized by a significant one-time increase during the day of the load in the morning hours and its deep decline at the end of the day, and the peak zone – by relatively small rises (to the maximum load level) and recessions (to the level of the intermediate zone) of the load in the daytime hours. Usually there are one or two maximum of electricity consumption: morning and evening. The first is most often associated with the morning shift of work of industrial enterprises. The second combines the consumption of workers in the evening shift of enterprises with the consumption of electricity in the residential sector and in the field of consumer services. As a result, the second peak in its magnitude always exceeds the first [25].

In the general case, the daily load curve of the power system alternates between dips, rises, recessions and peaks, which determine its overall uneven nature and is the sum of the daily load diagrams of various consumers (see Figure 3.4).

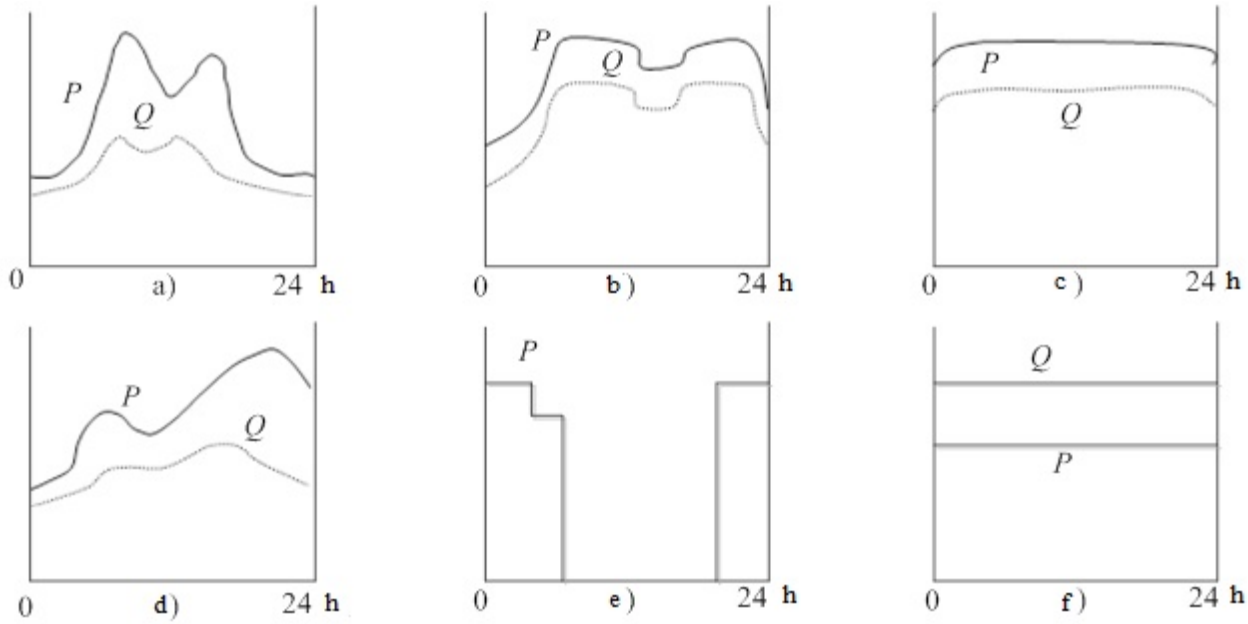


Figure 3.4 – Daily diagrams of active and reactive load:

a – one-shift enterprise; b – two-shift enterprise; c – three-shift enterprise; d – residential load; e – street lighting; f – water supply system and pumping stations [27]

The effectiveness of coverage of uneven load diagrams of the power system, primarily, is determined by the composition and characteristics of power generating units of the power plants. The effect of the possible alignment of the load diagram should be received by each of the three participants in this process: state, power system and consumers. In this regard, the alignment of the load diagram of the power system can not be an involuntary, random process, but it requires targeted measures with appropriate material and financial support.

# 4 DEVELOPMENT OF COMBINED METHOD OF DATA RECOVERY

Each enterprise has a different nature and different amounts of electricity consumption. Because of this, the load diagrams of all enterprises differ from each other. The use of a specific data approximation method in all enterprises will yield different results, occasionally – unsatisfactory results. As a result, it is necessary to develop a combined method, which will take into account the peculiarities of the electricity consumption of each enterprise.

Depending on the type of function under study, it is possible to use local or global methods. If there are sharp peaks in the function, it is advisable to use local methods. In the study of a function by local methods, it is divided into several segments and these segments are considered separately. When applying global methods, the function is considered as a unit on the whole interval and one characteristic is constructed for it.

In this scientific paper, it is considered an enterprise that consumes natural gas and electricity, generating ammonia. In the ammonia section, two ammonia units of the same power and equipment are installed, each of which can produce 25 tons of ammonia per hour.

In production, natural gas and air are raw materials. The technological process consists of the following stages:

- high-temperature conversion (cracking) of natural gas, which includes the compilation of natural gas and burning it with oxygen to form a convertible gas, consisting mainly of hydrogen and carbon monoxide. Oxygen comes from the air distribution unit;
- two-stage catalytic conversion of carbon monoxide;
- gas cleaning from carbon dioxide;
- gas flushing with liquid nitrogen from the air distribution unit;

– ammonia synthesis – the nitrogen-water mixture is compressed and fed into the synthesis department. After condensation, liquid ammonia comes into the collector and then to the liquid ammonia storage facility.

The oxygen needed for the conversion of methane, and the nitrogen needed to prepare the nitrogen-hydrogen mixture and to flush the converted gas from carbon monoxide, are extracted from the air by its distribution at low temperatures using deep-cooling cycles. The main electrical consumers in the production of ammonia are ammonia synchronous low-speed engines of high-pressure piston compressors, turbo-compressors supplying air and natural gas.

The main stages of ammonia production are as follows: the stages of reforming, conversion, absorption, methanation, compression, ammonia synthesis, ammonia condensation, degassing and ammonia dispersion.

As an example, the data for two months of operation of the ammonia section are considered. Technological changes in the production of ammonia did not occur.

## 4.1 Data recovery with the use of local methods

Data recovery was carried out by sorting the volume of ammonia production from the minimum to the maximum value. Then the sample was evaluated for a smooth change in the levels of resource consumption (energy and gas). In the case of chaotic change in parameters, the initially distorted values were excluded (in our case, these are the 2 first indicators).

Then, in each sample of values, deviations of samples from the initial value are determined within their limits.

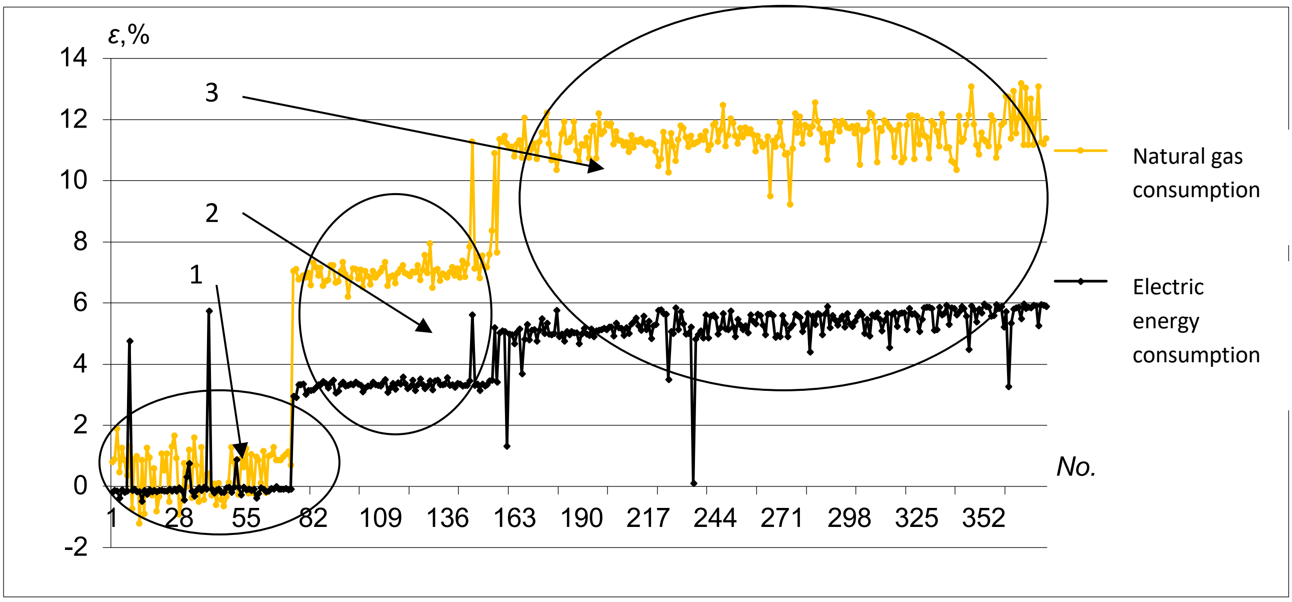


Figure 4.1 – Deviation of the values of the samples relative to the original value within the studied data sample

From Figure 4.1 it follows that the data is changing in discrete steps and it is necessary to sort the information by segments. Let us show them in a more representative form.

The description of the values of the first segment can be given as a range [-1; 2], but the accuracy of the calculations will first decrease by 3%.

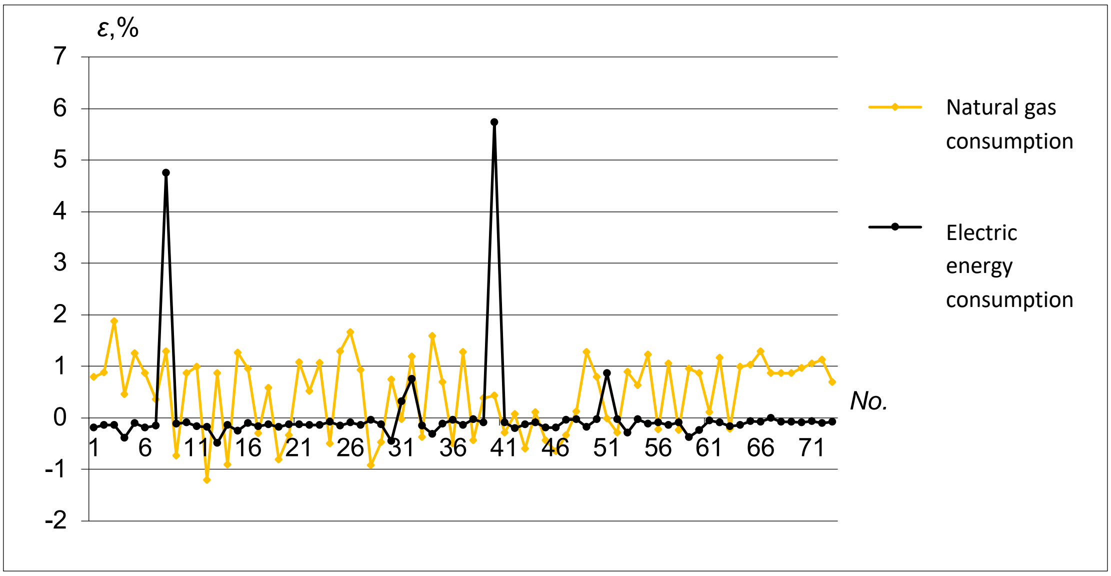


Figure 4.2 – Deviation of the values of the samples in relation to the initial value within the studied data sample when the ammonia production is changed from the minimum value to 5 tons (segment 1 of Figure 4.1)

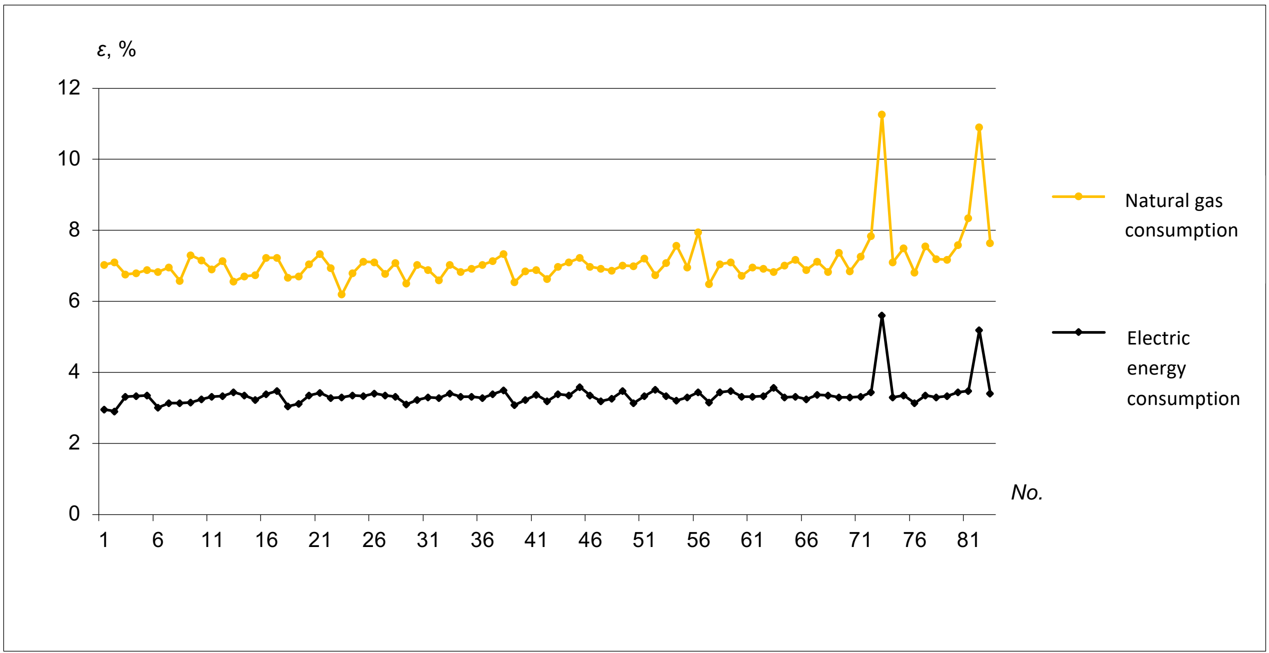


Figure 4.3 – Deviation of the values of the samples in relation to the initial value within the studied data sample when the ammonia production is changed from 5 to 10 tons (segment 2 of Figure 4.1)

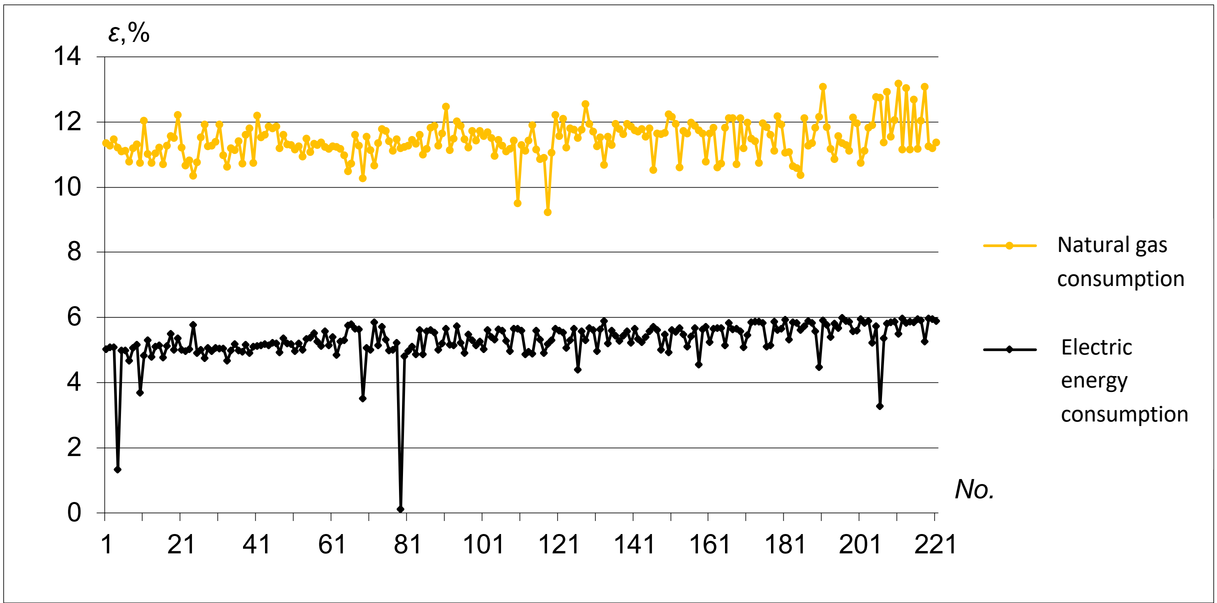


Figure 4.4 – Deviation of the values of the samples in relation to the initial value within the studied data sample when the ammonia production is changed from 10 tons through the maximum value (segment 3 of Figure 4.1)

From Figures 4.3 and 4.4 it follows that with a known sense of ammonia production, it is possible to determine the amount of electricity consumed and double-check the results by the amount of natural gas consumed. In these cases, the resource costs are described by a linear law.

From Figure 4.2 it follows that the energy consumption is linear in relation to the volume of ammonia production, but the level of gas consumption is step-like (sharply variable).

It should be noted that in all figures 4.2 – 4.4 there are values that do not fall under the description of the general laws (segment 1 – two, segment 2 – two, and segment 3 – three explicitly and three inexplicitly expressed values).

With a small volume of ammonia production from the minimum value up to 5 tons in relation to the initial value of the sample:

- natural gas consumption (described by expression):

$$y_i = 0,201 \cdot x_i + 0,301;$$

- electricity consumption is calculated according to the following formula:

$$y_i = 0,065 \cdot x_i.$$

With an average volume of ammonia production from 5 through 10 tons in relation to the initial value of the sample:

- natural gas consumption is determined as:

$$y_i = 0,366 \cdot x_i + 3,914;$$

- electricity consumption is given as:

$$y_i = 0,108 \cdot x_i - 0,88.$$

With a large volume of ammonia production from 10 tons through the maximum value in relation to the initial value of the sample:

- natural gas consumption determined as:

$$y_i = 0,26 \cdot x_i + 8,046;$$

- electricity consumption given as:

$$y_i = 0,324 \cdot x_i - 2,3.$$

With regard to the above mentioned, the initial values of gas consumption in all cases is 42.786 m$^3$ and the segment's electricity consumption (see Figure 4.1), which respectively are as follows:

- with a small volume of ammonia production – 31.019 MW;
- with an average volume of ammonia production – 34.3 MW;
- with a large volume of ammonia production – 34.424 MW.

Table 4.1 – Maximum and minimum percentage of relative error

| Gas | Electricity |
|---|---|
| 7.57 | 8.02 |
| -10.73 | -14.93 |

After that, a re-check of electricity consumption by the amount of consumed natural gas was carried out. The algorithm is similar to the previous one:

1. The sorting by volume of natural gas consumption from the minimum to the maximum value was carried out.
2. In each sample of values, deviations of samples from the initial value are determined within their limits.
3. The jumps of the energy consumption diagram are estimated.

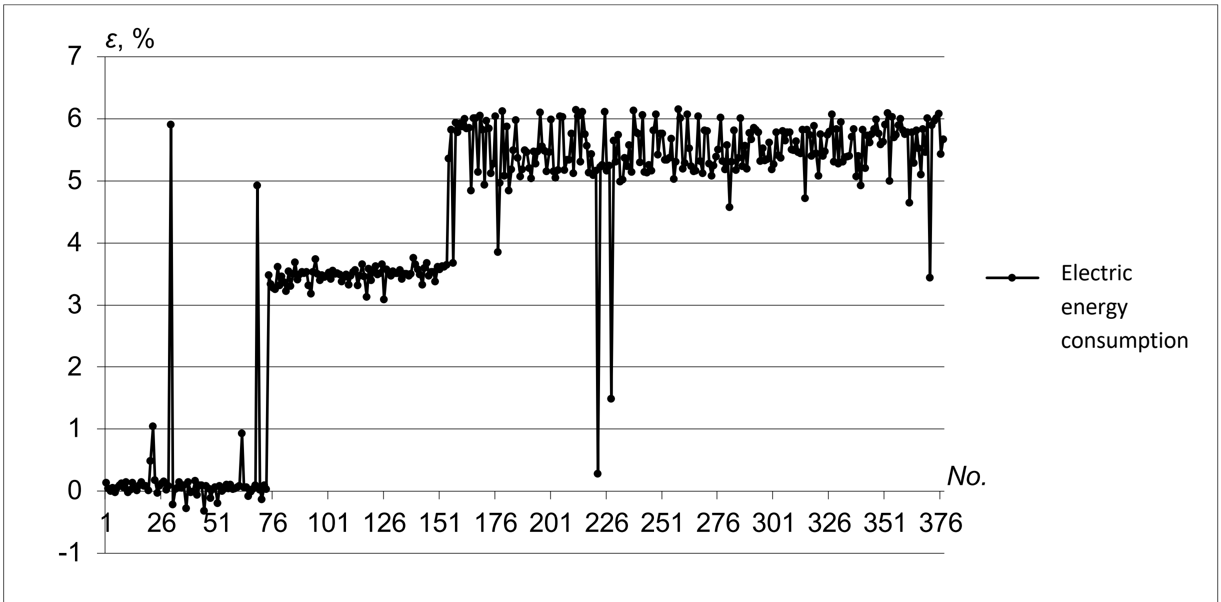

Figure 4.5 – Deviation of the values of electricity consumption in relation to the initial value, taking into account the sorting

Figure 4.5 shows that in order to increase the accuracy of setting the level of energy consumption, it is necessary to remove at least two values from the first segment, and from two to four values from the third segment.

In this case, it is possible to use three equations with one initial value of power of 30.845 MW:

- $y_i = -0,029 \cdot x_i + 0,121$ - segment I;
- $y_i = 0,397 \cdot x_i + 0,265$ - segment II;
- $y_i = 0,071 \cdot x_i + 4,614$ - segment III.

The results of such a determination of values do not differ from the output values by more than ± 5%. But at the points that were excluded from the preliminary preparation of information (the first and third segments – two values each), and at the boundary points of the segments, the error in the results increases (-16.77; 15.89) %. That is, by eliminating points from each segment that do not fall under the description of the general law, we managed to achieve better results.

## 4.2 Data recovery with the use of global methods

We have data for two periods about the enterprise that consumes natural gas and electricity and produces ammonia. During these periods, no technological changes have occurred, that is, the characteristics of production are similar.

In the first period (the spring period) there were no failures and all accounting data were recorded. However, in the second period (the summer period), part of the data on electricity consumption was lost. There was a need for their recovery. The technological process for a given period has a similar character; then, having found the characteristics during the spring period, they can be used to recover data in the summer period.

Let us illustrate the dependence of the used power (see Figure 4.6) and the consumption of natural gas (see Figure 4.7) on the production of ammonia during the spring period.

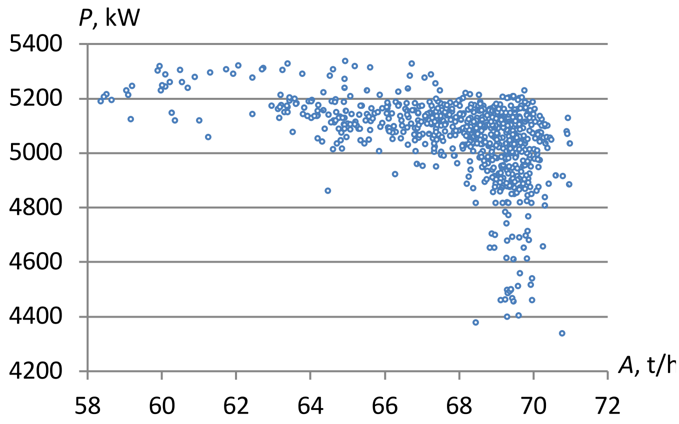

Figure 4.6 – Dependence of used power on ammonia production

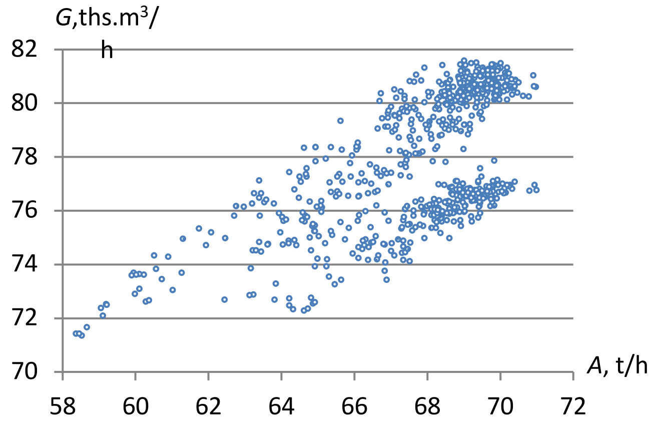

Figure 4.7 – Dependence of natural gas consumption on ammonia production

Since one value of the produced ammonia corresponds to a certain range of values of consumed natural gas and the power used, we will put in order the value of ammonia from minimum to maximum and for each of them we will find the range of values of natural gas and power. For convenience, we will work with dependences of minimum natural gas consumed on ammonia ($G_{min} = f(A)$), power used ($P_{min} = f(A)$), and dependences of the difference between the maximum and minimum value of natural gas on ammonia ($\Delta G = f(A)$) and power ($\Delta P = f(A)$). Figures 4.8 – 4.11 show the obtained dependences.

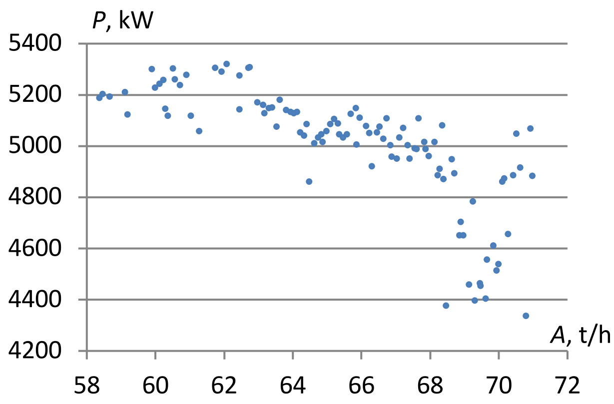


Figure 4.8 – Dependency $P_{min} = f(A)$

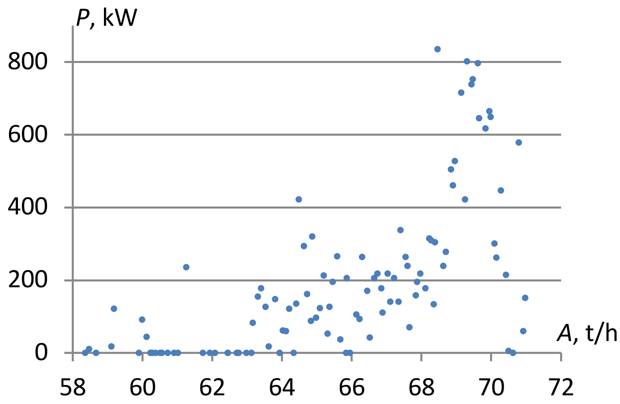


Figure 4.9 – Dependency $\Delta P = f(A)$

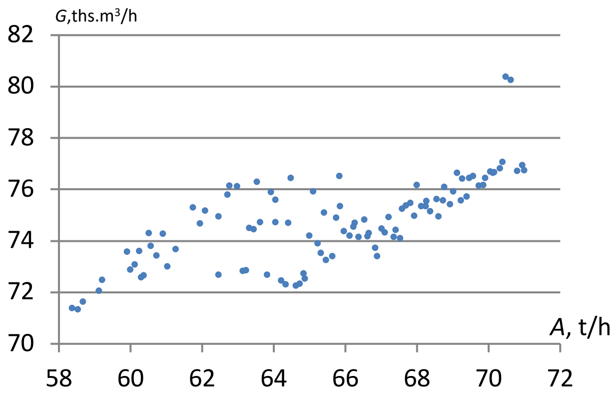


Figure 4.10 – Dependency $G_{min} = f(A)$

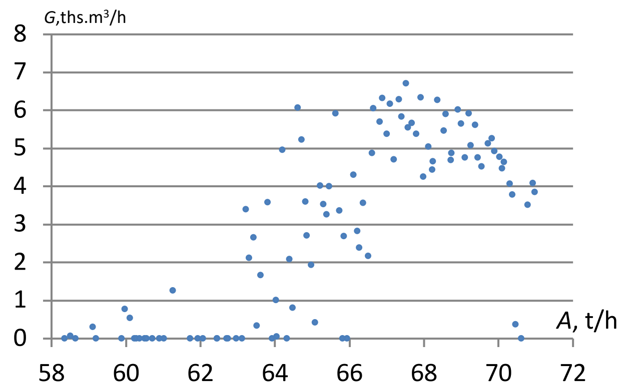


Figure 4.11 – Dependency $\Delta G = f(A)$

Using the software complex MATLAB, the dependency functions for all diagrams were found. for this purpose, we used the library of graphic models Curve Fitting Toolbox. This library contains the following widely used models for the approximation of table functions, namely:

– Polynomial – the polynomial coefficients are selected, the degree of which can vary from 1 to 9 inclusive:

$$y(x) = \sum_{i=0}^{n} p_i x^{n-i};$$

– Exponential – as an approximation function, one of the following is selected:

$$y(x) = ae^{bx};\ y(x) = ae^{bx} + ce^{dx};$$

– Fourier – the data are approaching by the segments of the Fourier series for $1 < n < 8$:

$$y(x) = a_0 + \sum_{i=1}^{n} \left( a_i \sin i\omega x + b_i \cos i\omega x \right);$$

- Gaussian – the model contains the following set of functions ($1 < n < 8$):

$$y(x) = \sum_{i=1}^{n} \frac{a_i}{e^{\left( \frac{(x-b_i)}{c_i} \right)^2}};$$

- Rational – the table function is approximated by the relation of two polynomials with degrees not exceeding 5 (not necessarily equal):

$$y(x) = \frac{\sum_{i=0}^{n} p_i x^{n-i}}{\sum_{i=0}^{m} q_i x^{m-i}}, \ q_0 = 1;$$

- Sum of Sin Function – approximating function is a segment of the following series ($1 < n < 8$):

$$y(x) = \sum_{i=1}^{n} a_i \sin\left( b_i x + c_i \right).$$

Once the model is built (the value of all coefficients is calculated), it is necessary to check its efficiency. As mentioned earlier, the criteria for model effectiveness are determined by the objectives of the modeling. A relative error was used to assess its effectiveness.

The relative error in estimating the value of a certain coefficient $c_i$ is defined as:

$$\varepsilon_{coeff}^{(i)} = \frac{\left| c_i - c_i^{(0)} \right|}{\left| c_i^{(0)} \right|},$$

in the case $c_i^{(0)} \neq 0$, where $c_i^{(0)}$ – the true value of this coefficient. If $c_i^{(0)} = 0$, the error of recovery of the coefficient value is defined as:

$$\varepsilon_{coeff}^{(i)} = \left| c_i \right|.$$

Also, the efficiency of building the model can be determined using the target function:

$$F = f \left| x_1 - x_0 \right| \to 0,$$

where $x_1$ is the true value of the function;

$x_0$ is the found value using approximation methods.

### 4.2.1 Construction of the dependence of used power on ammonia production

Let us consider the dependence $P_{min} = f(A)$. Using the Curve Fitting Toolbox, we find the dependency functions with the application of the Polynomial method.

Figure 4.12 shows a histogram with errors for the dependences $P_{min} = f(A)$ constructed with the use of the Polynomial method on different degrees.

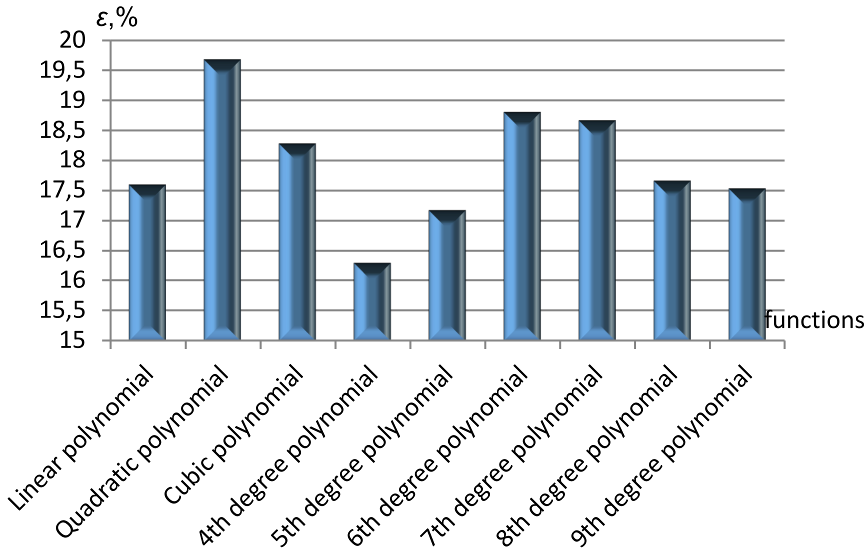


Figure 4.12 – Errors of the dependence $P_{min} = f(A)$ constructed with the use of the Polynomial method

Having compared the errors, we choose the dependence with the minimum values of ε, that is, in this case it is the dependence on the polynomial of the fourth degree, namely:

$$f(x) = p_1x^4 + p_2x^3 + p_3x^2 + p_4x + p_5;$$
$$p_1 = 0,227\ (6,501\cdot10^{-3};\ 0,448);$$
$$p_2 = -58,28\ (-115,5;\ -1,102);$$
$$p_3 = 5596\ (44,59;\ 1,115\cdot10^{4});$$
$$p_4 = -2,383\cdot10^{5}\ (-4,776\cdot10^{5};\ 966,6);$$
$$p_5 = 3,804\cdot10^{6}\ (-5,95\cdot10^{4};\ 7,667\cdot10^{6}).$$

The dependence function defined with the use of the Polynomial method is shown in Figure 4.13.

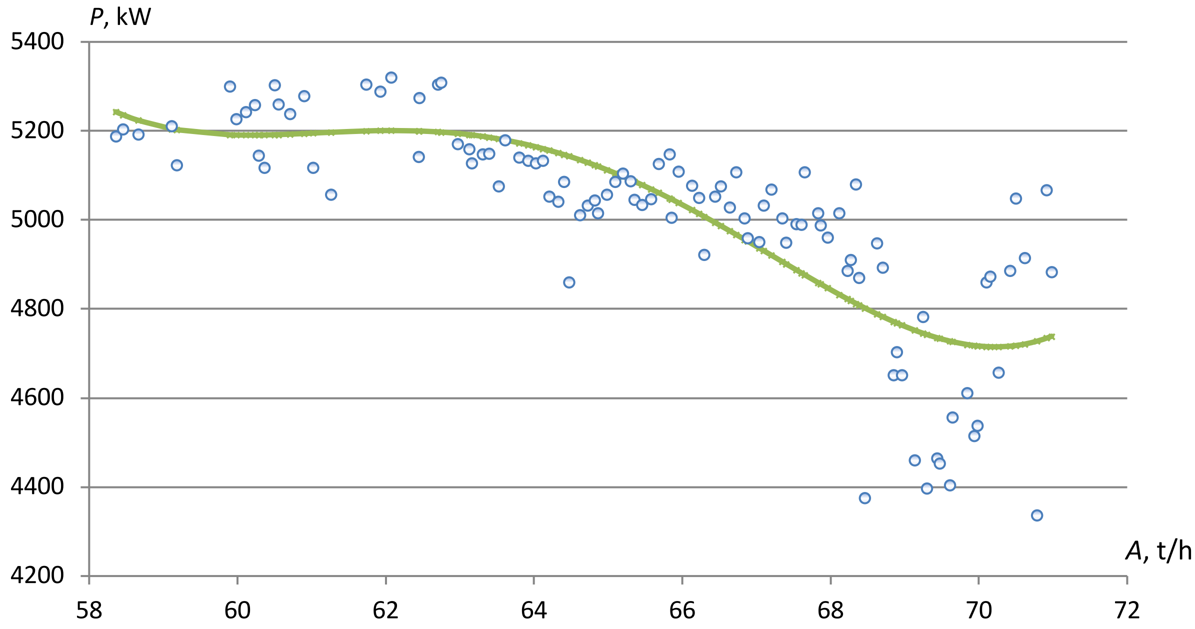


Figure 4.13 – The function of the dependence $P_{min} = f(A)$ defined with the use of the Polynomial method

Let us consider the dependences using the Exponential method. In Table 4.2, we present the errors for the dependence $P_{min} = f(A)$.

Table 4.2 – Relative errors of the dependence $P_{min} = f(A)$ using the Exponential method

| Exponentials | ε, % |
|---|---|
| $ae^{(bx)}$ | 17.47 |
| $ae^{(bx)} + ce^{(dx)}$ | 19.795 |

Having compared the relative errors, we choose the dependence in which it turned out to be minimal, namely:

$$f(x) = ae^{(bx)};$$
$$a = 9647 \; (8531; \; 1{,}076 \cdot 10^{4});$$
$$b = -0{,}01 \; (-0{,}012; \; -0{,}0083).$$

The function of the dependence $P_{min} = f(A)$ defined with the use of the Exponential method is shown in Figure 4.14.

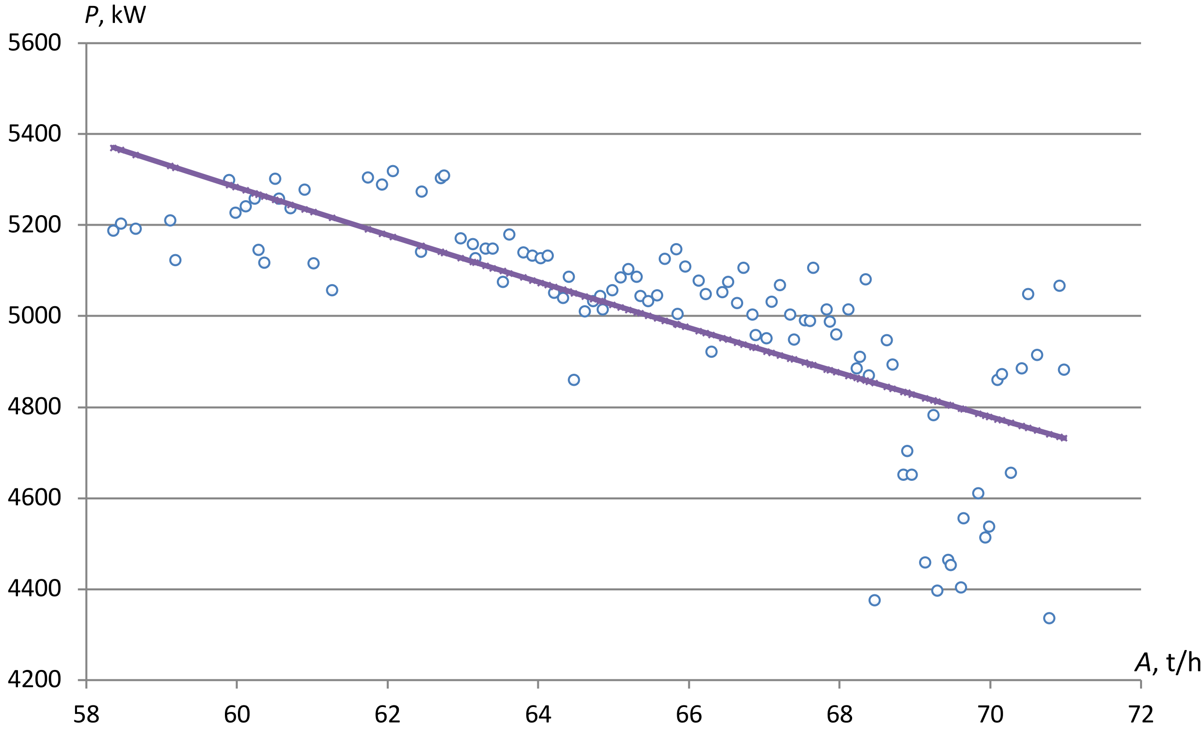


Figure 4.14 – The function of the dependence $P_{min} = f(A)$ defined with the use of the Exponential method

Let us consider the dependence $P_{min} = f(A)$ using the Fourier method. In table 4.3, we present the types of dependences under study.

Table 4.3 – Possible functions of the Fourier method

| No. | Fourier |
|---|---|
| 1 | $a_0 + a_1 \cdot \cos(x \cdot w) + b_1 \cdot \sin(x \cdot w)$ |
| 2 | $a_0 + a_1 \cdot \cos(x \cdot w) + b_1 \cdot \sin(x \cdot w) + a_2 \cdot \cos(2 \cdot x \cdot w) + b_2 \cdot \sin(2 \cdot x \cdot w)$ |
| 3 | $a_0 + a_1 \cdot \cos(x \cdot w) + b_1 \cdot \sin(x \cdot w) + ... + a_3 \cdot \cos(3 \cdot x \cdot w) + b_3 \cdot \sin(3 \cdot x \cdot w)$ |
| 4 | $a_0 + a_1 \cdot \cos(x \cdot w) + b_1 \cdot \sin(x \cdot w) + ... + a_4 \cdot \cos(4 \cdot x \cdot w) + b_4 \cdot \sin(4 \cdot x \cdot w)$ |
| 5 | $a_0 + a_1 \cdot \cos(x \cdot w) + b_1 \cdot \sin(x \cdot w) + ... + a_5 \cdot \cos(5 \cdot x \cdot w) + b_5 \cdot \sin(5 \cdot x \cdot w)$ |

| | |
|---|---|
| 6 | $a_0+a_1\cdot\cos(x\cdot w)+b_1\cdot\sin(x\cdot w)+...+a_6\cdot\cos(6\cdot x\cdot w)+b_6\cdot\sin(6\cdot x\cdot w)$ |
| 7 | $a_0+a_1\cdot\cos(x\cdot w)+b_1\cdot\sin(x\cdot w)+...+a_7\cdot\cos(7\cdot x\cdot w)+b_7\cdot\sin(7\cdot x\cdot w)$ |
| 8 | $a_0+a_1\cdot\cos(x\cdot w)+b_1\cdot\sin(x\cdot w)+...+a_8\cdot\cos(8\cdot x\cdot w)+b_8\cdot\sin(8\cdot x\cdot w)$ |

Figure 4.15 shows a histogram with relative errors for the dependence $P_{min}$ = $f(A)$ constructed with the use of the Fourier method for different functions.

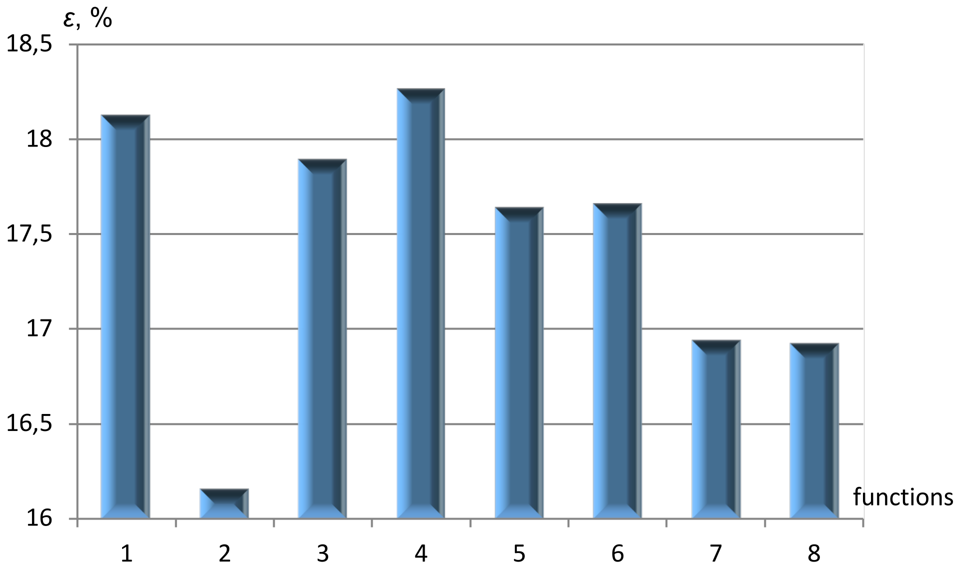


Figure 4.15 – Relative errors of the dependence $P_{min} = f(A)$ constructed with the use of the Fourier method

Having compared the errors, we choose the following function:

$$f(x)=a_0+a_1\cdot\cos(x\cdot w)+b_1\cdot\sin(x\cdot w)+a_2\cdot\cos(2\cdot x\cdot w)+b_2\cdot\sin(2\cdot x\cdot w);$$

$$a_0=5024(4993;\ 5055);$$

$$a_1=-189,5(-554,9;\ 175,9);$$

$$b_1=143,7(-352,9;\ 640,4);$$

$$a_2=-109(-351,1;\ 133,1);$$

$$b_2=42,21(-521,2;\ 605,7);$$

$$w=0,445(0,405;\ 0,485).$$

The function of the dependence $P_{min} = f(A)$ defined with the use of the Fourier method is shown in Figure 4.16.

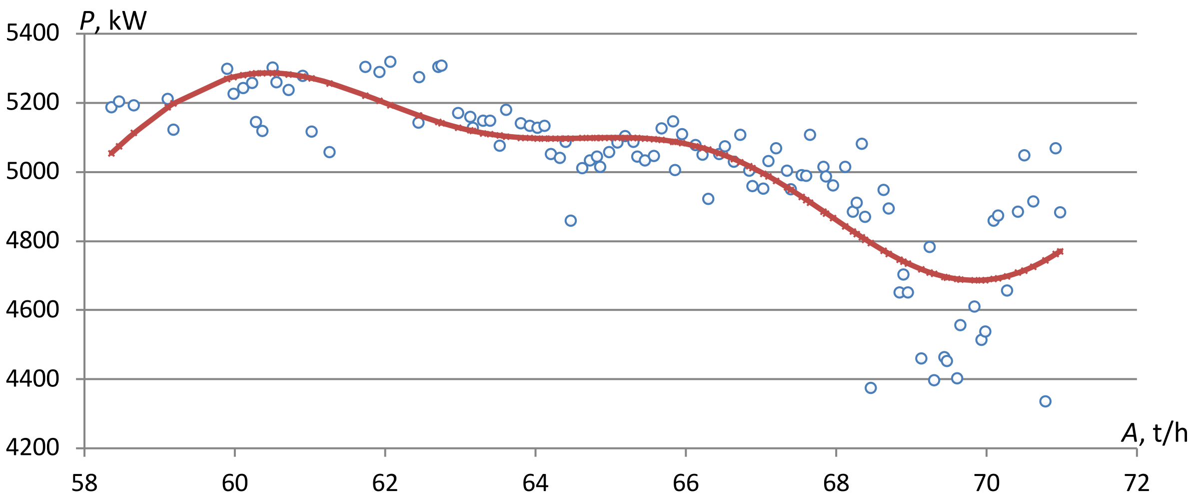


Figure 4.16 – The function of the dependence $P_{min} = f(A)$ defined with the use of the Fourier method

Let us consider the dependence $P_{min} = f(A)$ using the Gaussian method. In table 4.4, we present the types of dependences under study.

Table 4.4 – Possible functions of the Gaussian method

| No. | Gaussian | No. | Gaussian |
|---|---|---|---|
| 1 | $a_1 e^{-\left(\frac{x-b_1}{c_1}\right)^2}$ | 5 | $a_1 e^{-\left(\frac{x-b_1}{c_1}\right)^2} + \ldots + a_5 e^{-\left(\frac{x-b_5}{c_5}\right)^2}$ |
| 2 | $a_1 e^{-\left(\frac{x-b_1}{c_1}\right)^2} + a_2 e^{-\left(\frac{x-b_2}{c_2}\right)^2}$ | 6 | $a_1 e^{-\left(\frac{x-b_1}{c_1}\right)^2} + \ldots + a_6 e^{-\left(\frac{x-b_6}{c_6}\right)^2}$ |
| 3 | $a_1 e^{-\left(\frac{x-b_1}{c_1}\right)^2} + \ldots + a_3 e^{-\left(\frac{x-b_3}{c_3}\right)^2}$ | 7 | $a_1 e^{-\left(\frac{x-b_1}{c_1}\right)^2} + \ldots + a_7 e^{-\left(\frac{x-b_7}{c_7}\right)^2}$ |
| 4 | $a_1 e^{-\left(\frac{x-b_1}{c_1}\right)^2} + \ldots + a_4 e^{-\left(\frac{x-b_4}{c_4}\right)^2}$ | 8 | $a_1 e^{-\left(\frac{x-b_1}{c_1}\right)^2} + \ldots + a_8 e^{-\left(\frac{x-b_8}{c_8}\right)^2}$ |

Figure 4.17 shows a histogram with relative errors for the dependences $P_{min} = f(A)$ constructed with the use of the Gaussian method on different functions.

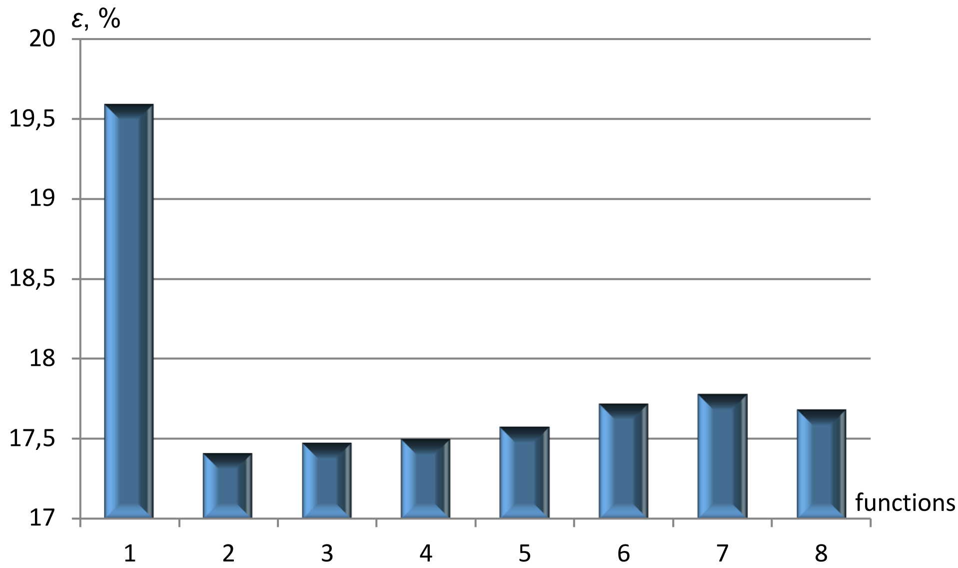

Figure 4.17 – Relative errors of the dependence $P_{min} = f(A)$ constructed with the use of the Gaussian method

Having compared the errors, we choose the following function:

$$f(x) = a_1 \cdot e^{-\left(\frac{x-b_1}{c_1}\right)^2} + a_2 \cdot e^{-\left(\frac{x-b_2}{c_2}\right)^2};$$

$$a_1 = 4966 \ \left(-1{,}068 \cdot 10^5;\ 1{,}167 \cdot 10^5\right);$$

$$b_1 = 59{,}79 \ \left(-148;\ 267{,}5\right);$$

$$c_1 = 17{,}01 \ \left(-170{,}4;\ 204{,}4\right);$$

$$a_2 = 2{,}178 \cdot 10^{16} \ \left(-3{,}784 \cdot 10^{21};\ 3{,}784 \cdot 10^{21}\right);$$

$$b_2 = 454{,}3 \ \left(-2{,}238 \cdot 10^6;\ 2{,}238 \cdot 10^6\right);$$

$$c_2 = 69{,}62 \ \left(-2{,}07 \cdot 10^5;\ 2{,}072 \cdot 10^5\right).$$

The function of the dependence $P_{min} = f(A)$ defined with the use of the Gaussian method is shown in Figure 4.18.

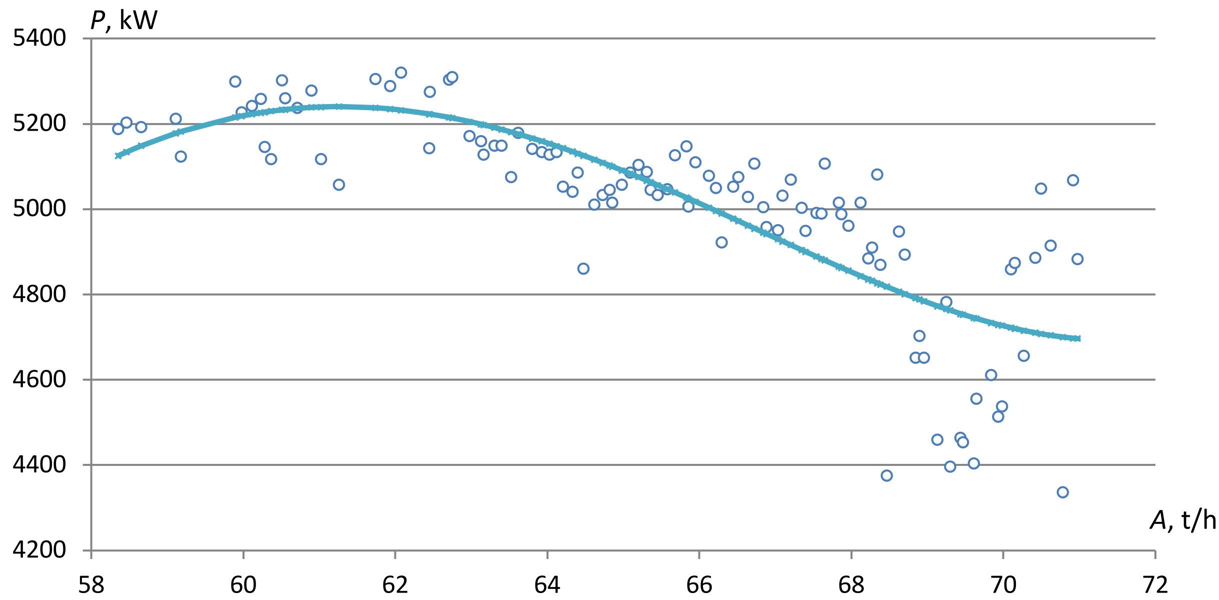


Figure 4.18 – The function of the dependence $P_{min} = f(A)$ defined with the use of the Gaussian method

Let us consider the dependence $P_{min} = f(A)$ using the Rational method. In table 4.5, we present the types of dependences under study.

Table 4.5 – Types of dependences using the Rational method

| No. | Rationals | |
|---|---|---|
| | Numerator | Denominator |
| 1 | 4th degree polynomial | Linear polynomial |
| 2 | 4th degree polynomial | Quadratic polynomial |
| 3 | 4th degree polynomial | Cubic polynomial |
| 4 | 4th degree polynomial | 5th degree polynomial |
| 5 | 5th degree polynomial | Linear polynomial |
| 6 | 5th degree polynomial | Quadratic polynomial |
| 7 | 5th degree polynomial | Cubic polynomial |
| 8 | 5th degree polynomial | 4th degree polynomial |

Figure 4.19 shows a histogram with relative errors for the dependences $P_{min}$ = $f(A)$ constructed with the use of the Rational method for different types.

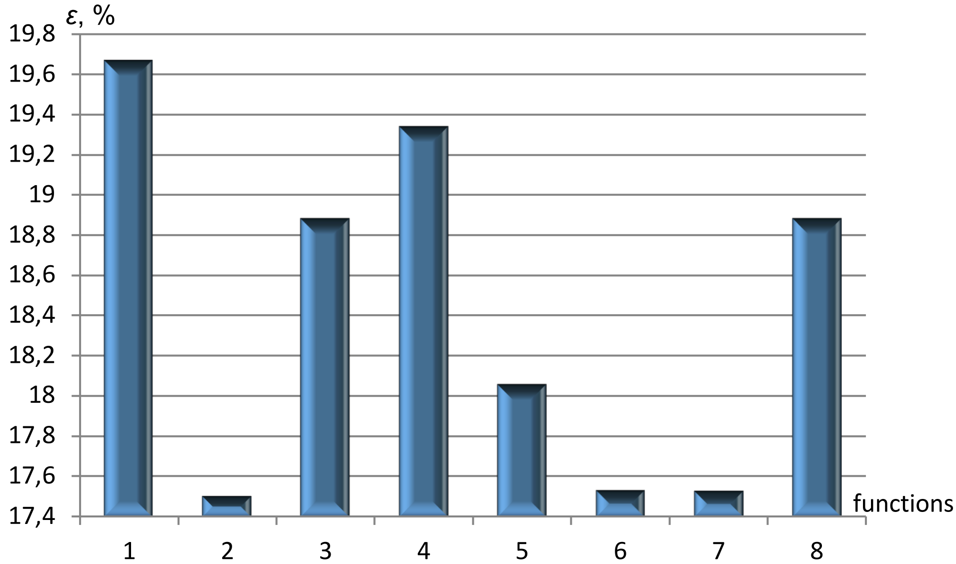


Figure 4.19 – Relative errors of the dependence $P_{min} = f(A)$ constructed with the use of the Rational method

Having compared the errors, we have the following function:

$$f(x) = (p_1 \cdot x^4 + p_2 \cdot x^3 + p_3 \cdot x^2 + p_4 \cdot x + p_5) / (x^2 + q_1 \cdot x + q_2);$$
$$p_1 = 3{,}658\ (-1014;\ 1021);$$
$$p_2 = -554{,}3\ (-2{,}328 \cdot 10^5;\ 2{,}317 \cdot 10^5);$$
$$p_3 = 2{,}092 \cdot 10^4\ (-1{,}948 \cdot 10^7;\ 1{,}952 \cdot 10^7);$$
$$p_4 = 1254\ (-7{,}294 \cdot 10^8;\ 7{,}294 \cdot 10^8);$$
$$p_5 = 49{,}4\ (-1{,}074 \cdot 10^{10};\ 1{,}074 \cdot 10^{10});$$
$$q_1 = -182{,}5\ (-3818;\ 3453);$$
$$q_2 = 7936\ (-2{,}522 \cdot 10^5;\ 2{,}68e \cdot 10^5).$$

The function of the dependence $P_{min} = f(A)$ defined with the use of the Rational method is shown in Figure 4.20.

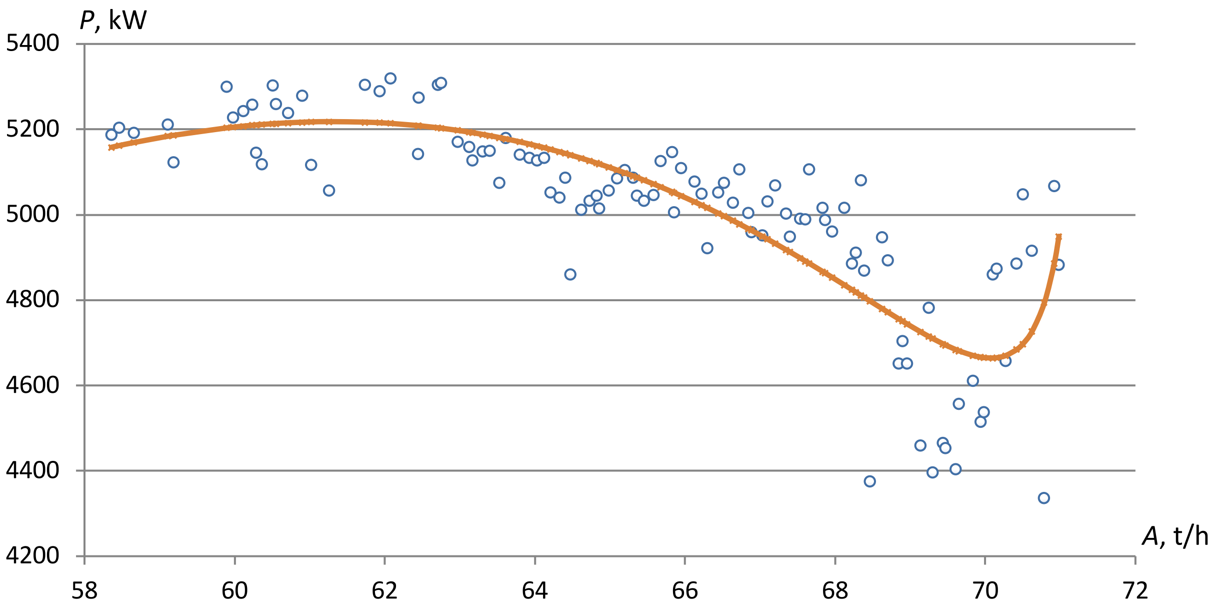


Figure 4.20 – The function of the dependence $P_{min} = f(A)$ defined with the use of the Rational method

Let us consider the dependence $P_{min} = f(A)$ using the Sum of Sin Function method. In table 4.6, we present the functions of dependences under study.

Table 4.6 - Types of dependences using the Sum of Sin Function method

| No. | Sum of Sin Functions |
|---|---|
| 1 | $a_1 \cdot \sin(b_1 \cdot x + c_1)$ |
| 2 | $a_1 \cdot \sin(b_1 \cdot x + c_1) + a_2 \cdot \sin(b_2 \cdot x + c_2)$ |
| 3 | $a_1 \cdot \sin(b_1 \cdot x + c_1) + ... + a_3 \cdot \sin(b_3 \cdot x + c_3)$ |
| 4 | $a_1 \cdot \sin(b_1 \cdot x + c_1) + ... + a_4 \cdot \sin(b_4 \cdot x + c_4)$ |
| 5 | $a_1 \cdot \sin(b_1 \cdot x + c_1) + ... + a_5 \cdot \sin(b_5 \cdot x + c_5)$ |
| 6 | $a_1 \cdot \sin(b_1 \cdot x + c_1) + ... + a_6 \cdot \sin(b_6 \cdot x + c_6)$ |
| 7 | $a_1 \cdot \sin(b_1 \cdot x + c_1) + ... + a_7 \cdot \sin(b_7 \cdot x + c_7)$ |
| 8 | $a_1 \cdot \sin(b_1 \cdot x + c_1) + ... + a_8 \cdot \sin(b_8 \cdot x + c_8)$ |

Figure 4.21 shows a histogram with relative errors for the dependences $P_{min}$ = $f(A)$ constructed with the use of the Sum of Sin Function method for different types.

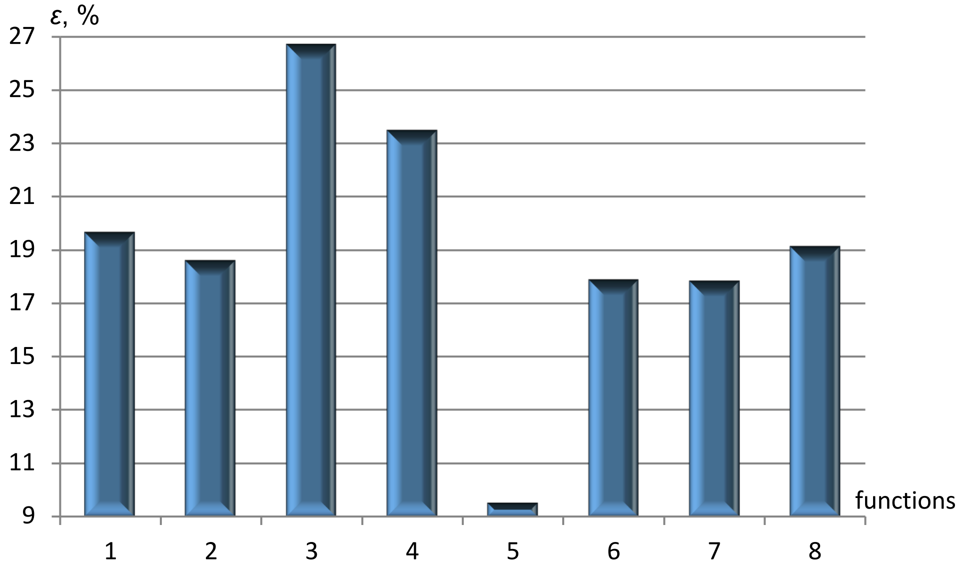


Figure 4.21 – Relative errors of the dependence $P_{min} = f(A)$ constructed with the use of the Sum of Sin Function method

Having compared the errors, we choose the following function:

$$f(x) = a_1 \cdot \sin(b_1 \cdot x + c_1) + a_2 \cdot \sin(b_2 \cdot x + c_2) + a_3 \cdot \sin(b_3 \cdot x + c_3) + a_4 \cdot \sin(b_4 \cdot x + c_4) + a_5 \cdot \sin(b_5 \cdot x + c_5);$$

$$a_1 = 8334\ \left(-1{,}401 \cdot 10^7;\ 1{,}402 \cdot 10^7\right);\ b_1 = 0{,}243\ (-201{,}9;\ 202{,}4);\ c_1 = -1{,}603\ \left(-1{,}316 \cdot 10^4;\ 1{,}315 \cdot 10^4\right);$$

$$a_2 = 3594\ \left(-1{,}379 \cdot 10^7;\ 1{,}379 \cdot 10^7\right);\ b_2 = 0{,}451\ (-408{,}7;\ 409{,}6);\ c_2 = 0{,}645\ \left(-2{,}656 \cdot 10^4;\ 2{,}656 \cdot 10^4\right);$$

$$a_3 = 485{,}4\ \left(-2{,}857 \cdot 10^5;\ 2{,}867 \cdot 10^5\right);\ b_3 = 0{,}972\ (-13{,}54;\ 15{,}49);\ c_3 = 1{,}314\ (-958{,}8,\ 961{,}5);$$

$$a_4 = 182{,}2\ \left(-1{,}761 \cdot 10^4;\ 1{,}797 \cdot 10^4\right);\ b_4 = 1{,}984\ (-11{,}45;\ 15{,}41);\ c_4 = -1{,}458(-872{,}6,\ 869{,}6);$$

$$a_5 = 297{,}6\ \left(-3{,}859 \cdot 10^4;\ 3{,}919 \cdot 10^4\right);\ b_5 = 1{,}518\ (-65{,}05;\ 68;08);\ c_5 = 0{,}507\ (-4318;\ 4319).$$

The function of the dependence $P_{min} = f(A)$ defined with the use of the Sum of Sin Function method is shown in Figure 4.22.

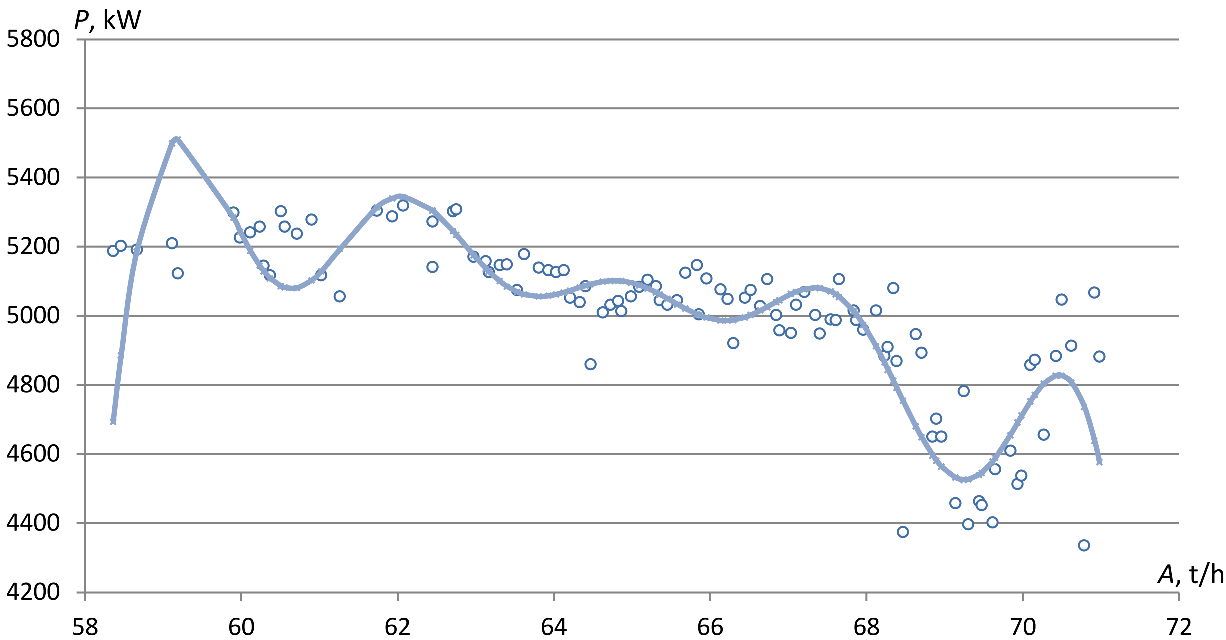


Figure 4.22 – The function of the dependence $P_{min} = f(A)$ constructed with the use of the Sum of Sin Function method

Types of functions with minimal errors are presented in Table 4.7. To compare the accuracy of data recovery, Figure 4.23 shows a histogram with the errors of these methods.

Table 4.7 – Type of functions with minimal relative errors

| Method | Function |
|---|---|
| Polynomials | $f(x) = p_1 x^4 + p_2 x^3 + p_3 x^2 + p_4 x + p_5$ |
| Exponentials | $f(x) = ae^{(bx)}$ |
| Fourier | $f(x) = a_0 + a_1 \cdot \cos(x \cdot w) + b_1 \cdot \sin(x \cdot w) +$ $+ a_2 \cdot \cos(2 \cdot x \cdot w) + b_2 \cdot \sin(2 \cdot x \cdot w)$ |
| Gaussian | $\mathrm{f(x)} = a_1 \cdot e^{-\left(\frac{x-b_1}{c_1}\right)^2} + a_2 \cdot e^{-\left(\frac{x-b_2}{c_2}\right)^2}$ |
| Rationals | $f(x) = (p_1 \cdot x^4 + p_2 \cdot x^3 + p_3 \cdot x^2 + p_4 \cdot x + p_5) / (x^2 + q_1 \cdot x + q_2)$ |
| Sum of Sin Functions | $f(x) = a_1 \cdot \sin(b_1 \cdot x + c_1) + a_2 \cdot \sin(b_2 \cdot x + c_2) +$ $+ a_3 \cdot \sin(b_3 \cdot x + c_3) + a_4 \cdot \sin(b_4 \cdot x + c_4) + a_5 \cdot \sin(b_5 \cdot x + c_5)$ |

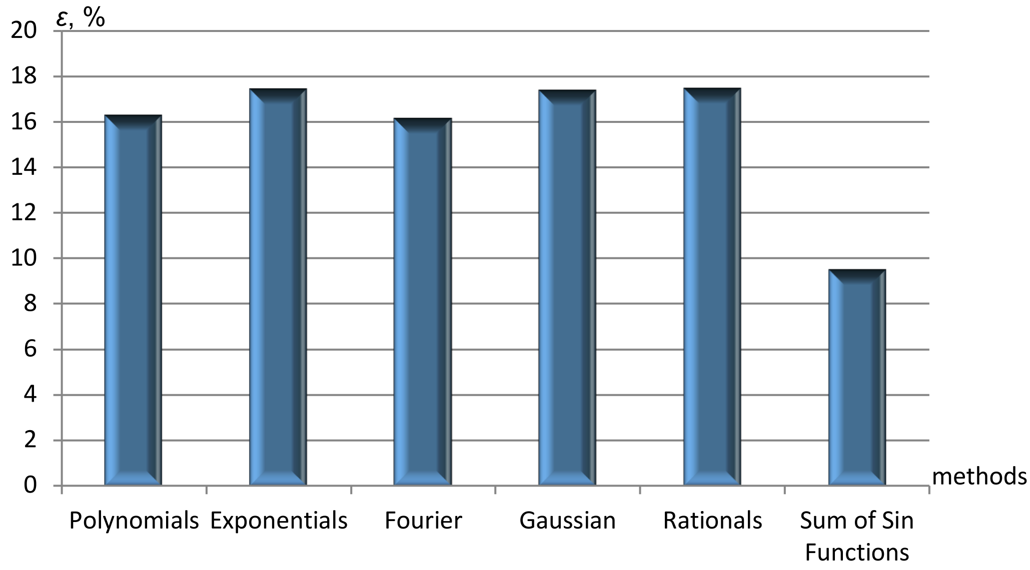


Figure 4.23 – Errors of function recovery methods

Figure 4.24 shows the type of functions that are used for data recovery.

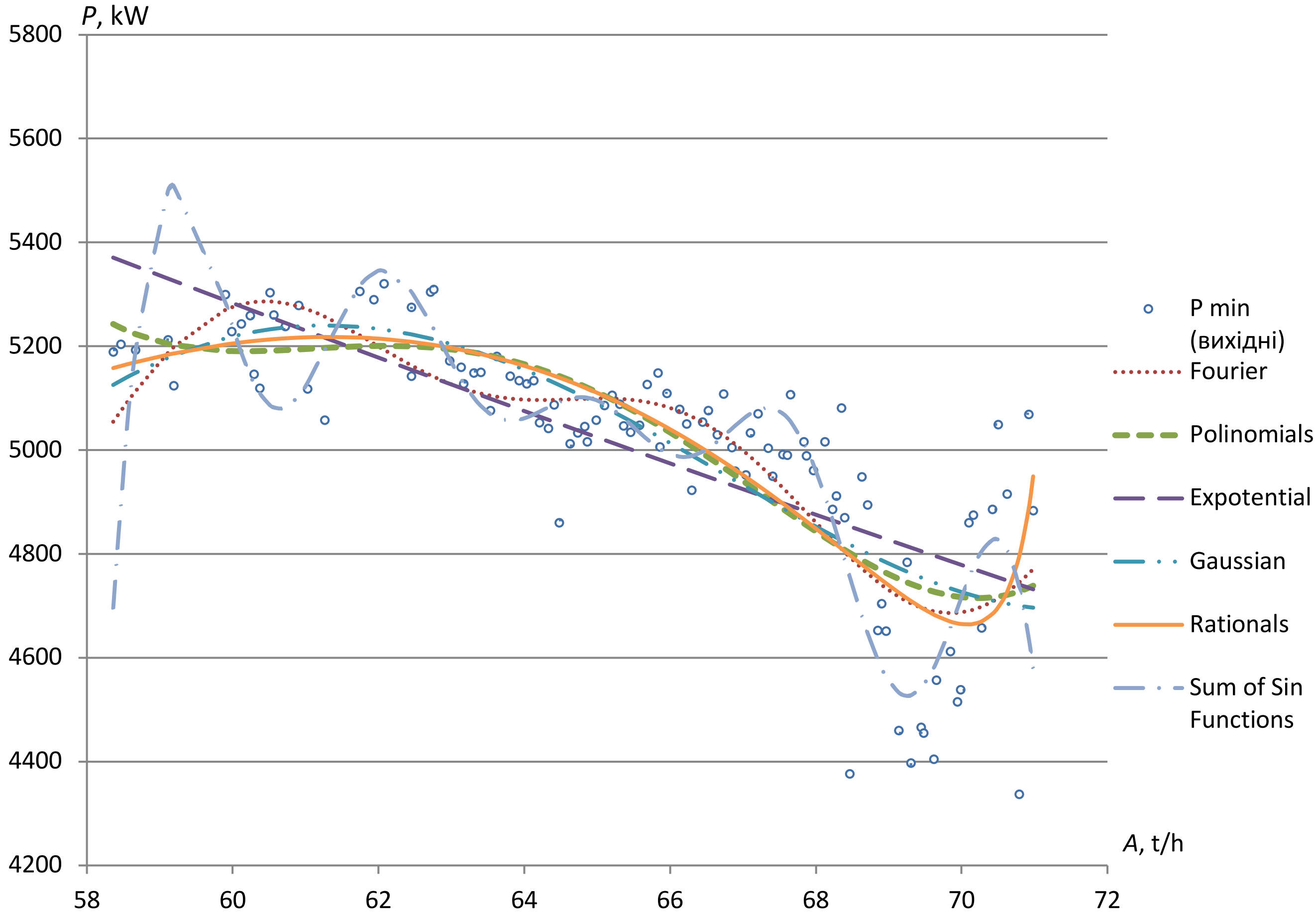


Figure 4.24 – Dependences of electricity consumption on ammonia production

After comparing the dependence of the used power on ammonia production, it can be seen that the Fourier method, compared to other methods, has the smallest error in the spring period. Therefore, the Fourier method is advisable to apply for recovering power consumption data that was lost during the summer period.

### 4.2.2 Construction of the dependence of natural gas consumption on ammonia production

Let us consider the dependence $G_{min} = f(A)$. Using the Curve Fitting Toolbox, we find the dependency functions with the application of the Polynomial method.

Figure 4.25 shows a histogram with relative errors for the dependences $G_{min} = f(A)$ constructed with the use of the Polynomial method for different types.

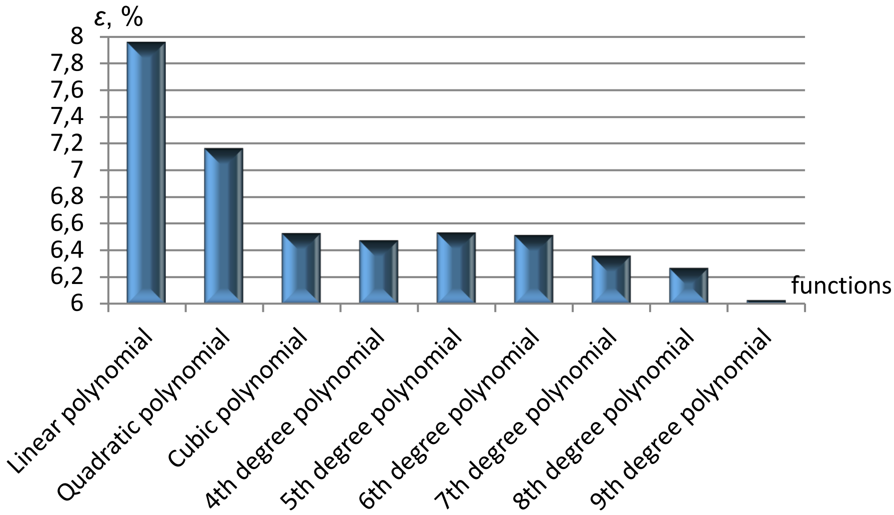


Figure 4.25 – Relative errors of the dependence $G_{min} = f(A)$ constructed with the use of the Polynomial method

Having compared the errors, we choose the dependence with the minimum value, i.e., it is the dependence on the polynomial of the ninth degree, namely:

$$f(x)=p_1\cdot x^9+p_2\cdot x^8+p_3\cdot x^7+p_4\cdot x^6+p_5\cdot x^5+p_6\cdot x^4+p_7\cdot x^3+p_8\cdot x^2+p_9\cdot x+p_{10};$$

$$p_1=-1{,}745\cdot 10^{-6}\ \left(-6{,}698\cdot 10^{-6};\ 3{,}207\cdot 10^{-6}\right);\ p_2=0{,}001\ \left(-1{,}883\cdot 10^{-3};\ 3{,}888\cdot 10^{-3}\right);$$

$$p_3=-0{,}256\ \left(-1{,}002;\ 0{,}491\right);\ p_4=37{,}99\ \left(-74{,}68;\ 150{,}7\right);$$

$$p_5=-3628\ \left(-1{,}455\cdot 10^{4};\ 7296\right);\ p_6=2{,}308\cdot 10^{5}\ \left(-4{,}749\cdot 10^{5};\ 9{,}365\cdot 10^{5}\right);$$

$$p_7=-9{,}781\cdot 10^{6}\ \left(-4{,}015\cdot 10^{7};\ 2{,}059\cdot 10^{7}\right);\ p_8=2{,}663\cdot 10^{8}\ \left(-5{,}737\cdot 10^{8};\ 1{,}106\cdot 10^{9}\right);$$

$$p_9=-4{,}225\cdot 10^{9}\ \left(-1{,}777\cdot 10^{10};\ 9{,}317\cdot 10^{9}\right);\ p_{10}=2{,}978\cdot 10^{10}\ \left(-6{,}721\cdot 10^{10};\ 1{,}268\cdot 10^{11}\right).$$

The function of the dependence $G_{min}$ = $f(A)$ defined with the use of the Polynomial method is shown in Figure 4.26.

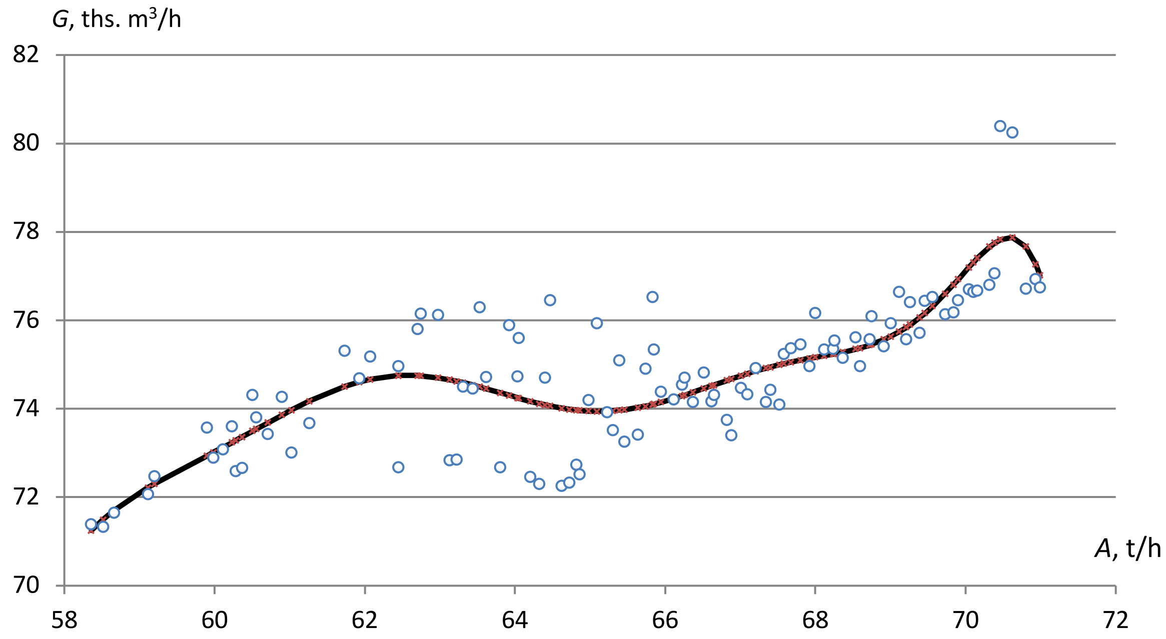


Figure 4.26 – The function of the dependence $G_{min} = f(A)$ defined with the use of the Polynomial method

Let us consider the dependences using the Exponential method. In Table 4.8, we present relative errors for the dependence $G_{min} = f(A)$.

Table 4.8 – Relative errors of the dependence $G_{min} = f(A)$ using the Exponential method

| Exponentials | ε, % |
|---|---|
| $ae^{(bx)}$ | 7.47 |
| $ae^{(bx)}+ce^{(dx)}$ | 6.57 |

Having compared the errors, we choose the dependence in which it turned out to be minimal, namely:

$$f(x) = ae^{(bx)} + ce^{(dx)};$$
$$a = 63,96 \ (51,3; \ 76,63);$$
$$b = 2,258 \cdot 10^{-3} \ \left(-1 \cdot 10^{-3}; \ 5,516 \cdot 10^{-3}\right);$$
$$c = 2,373 \cdot 10^{-14} \ \left(-1,141 \cdot 10^{-12}; \ 1,189 \cdot 10^{-12}\right);$$
$$d = 0,457 \ (-0,226; \ 1,14).$$

The function of the dependence $G_{min} = f(A)$ defined with the use of the Exponential method is shown in Figure 4.27.

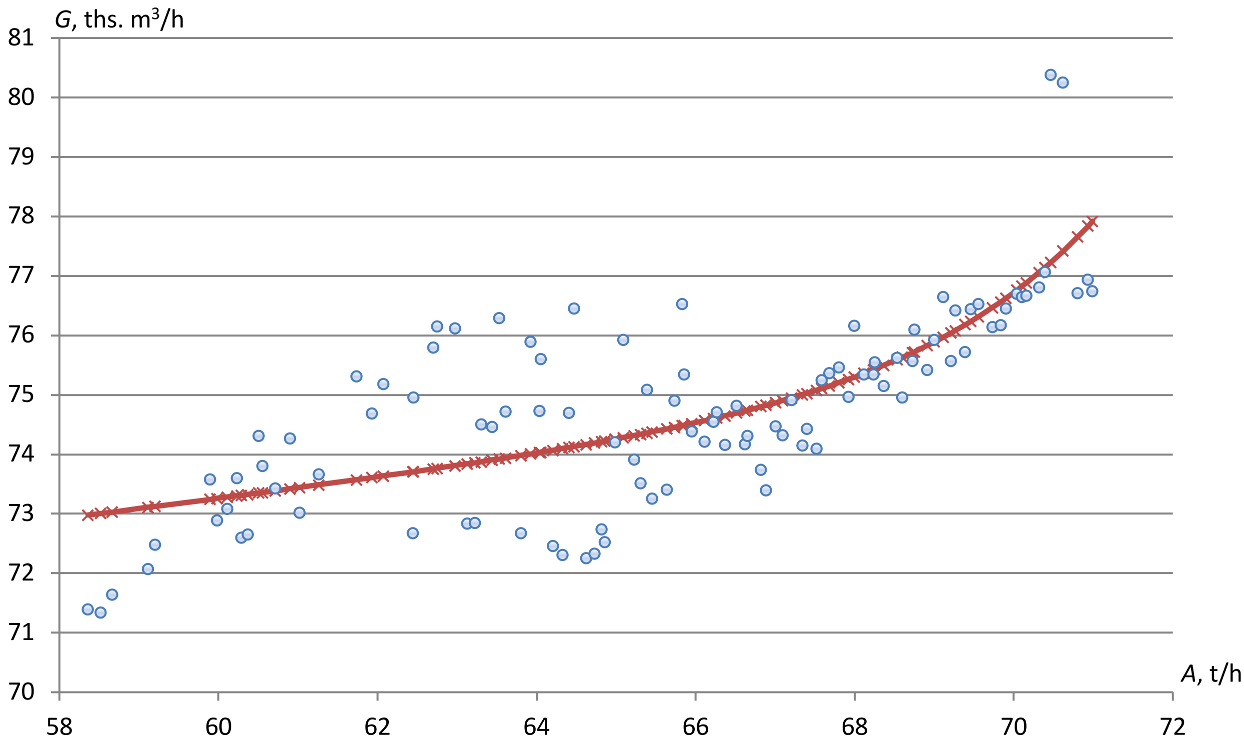


Figure 4.27 – The function of the dependence $G_{min} = f(A)$ defined with the use of the Exponential method

Let us consider the dependence $G_{min} = f(A)$ using the Fourier method. In table 4.3, we present the types of dependences under study.

Figure 4.28 shows a histogram with relative errors for the dependences $G_{min} = f(A)$ constructed with the use of the Fourier method for different types.

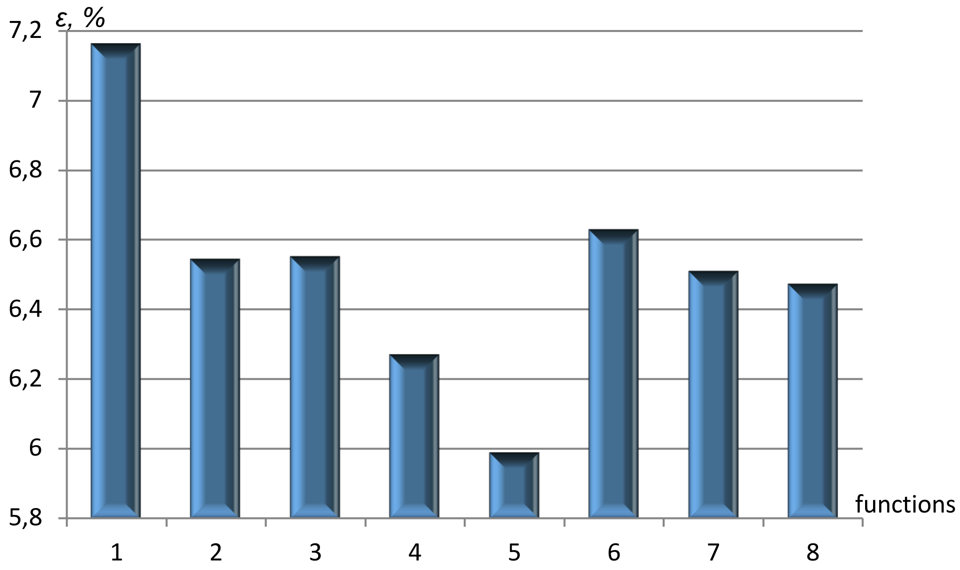


Figure 4.28 – Relative errors of the dependence $G_{min} = f(A)$ constructed with the use of the Fourier method

Having compared the errors, we choose the following function:

$$f(x) = a_0 + a_1 \cdot \cos(x \cdot w) + b_1 \cdot \sin(x \cdot w) + a_2 \cdot \cos(2 \cdot x \cdot w) + b_2 \cdot \sin(2 \cdot x \cdot w) + a_3 \cdot \cos(3 \cdot x \cdot w) +$$
$$+ b_3 \cdot \sin(3 \cdot x \cdot w) + a_4 \cdot \cos(4 \cdot x \cdot w) + b_4 \cdot \sin(4 \cdot x \cdot w) + a_5 \cdot \cos(5 \cdot x \cdot w) + b_5 \cdot \sin(5 \cdot x \cdot w);$$

$$a_0 = -1{,}022 \cdot 10^{12} \ \left(-2{,}156 \cdot 10^{15};\ 2{,}154 \cdot 10^{15}\right);$$
$$a_1 = -1{,}796 \cdot 10^{11} \ \left(-2{,}213 \cdot 10^{14};\ 2{,}209 \cdot 10^{14}\right);$$
$$b_1 = 1{,}695 \cdot 10^{12} \ \left(-3{,}635 \cdot 10^{15};\ 3{,}639 \cdot 10^{15}\right);$$
$$a_2 = 9{,}542 \cdot 10^{11} \ \left(-2{,}154 \cdot 10^{15};\ 2{,}156 \cdot 10^{15}\right);$$
$$b_2 = 2{,}044 \cdot 10^{11} \ \left(-2{,}44 \cdot 10^{14};\ 2{,}444 \cdot 10^{14}\right);$$
$$a_3 = 1{,}142 \cdot 10^{11} \ \left(-1{,}293 \cdot 10^{14};\ 1{,}295 \cdot 10^{14}\right);$$
$$b_3 = -3{,}487 \cdot 10^{11} \left(-8{,}559 \cdot 10^{14};\ 8{,}552 \cdot 10^{14}\right).$$

The function of the dependence $G_{min} = f(A)$ defined with the use of the Fourier method is shown in Figure 4.29.

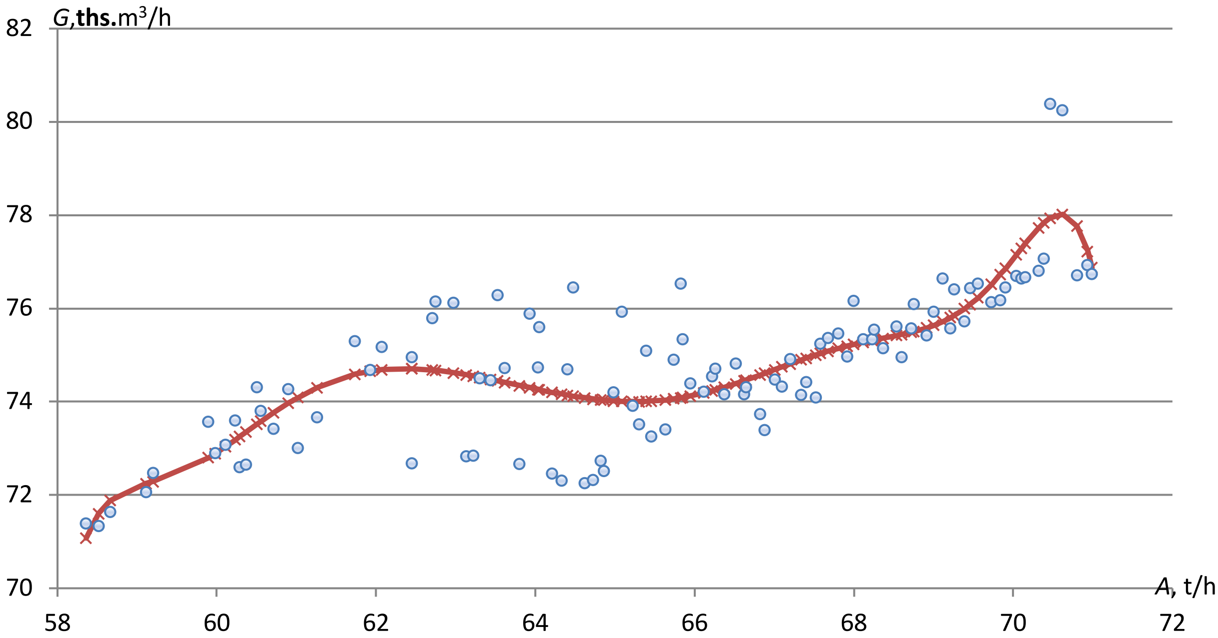


Figure 4.29 – The function of the dependence $G_{min}$ = f(A) defined with the use of the Fourier method

Let us consider the dependence of natural gas consumption on ammonia production using the Gaussian method. In table 4.4, we present the types of dependences under study.

Figure 4.30 shows a histogram with relative errors for the dependences $G_{min} = f(A)$ constructed with the use of the Gaussian method for functions of different types.

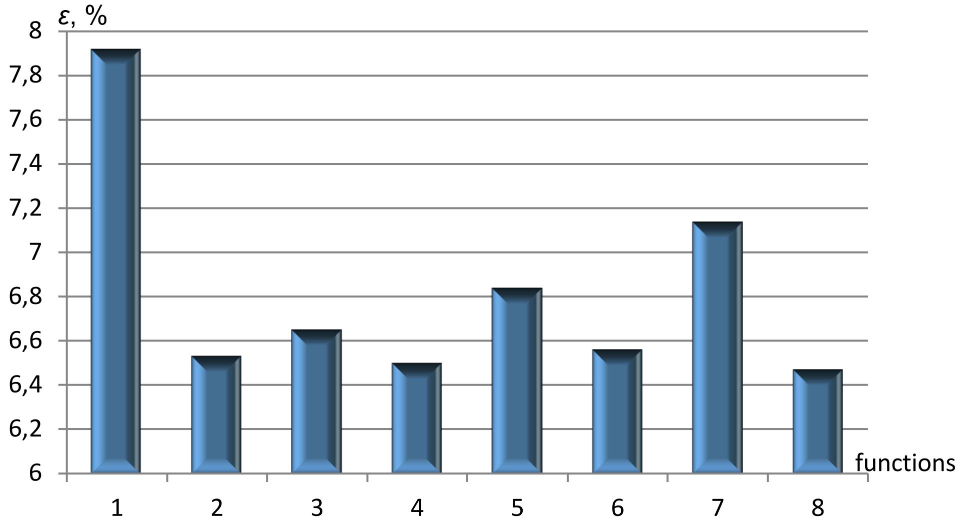


Figure 4.30 – Relative errors of the dependence $G_{min}$ = f(A) constructed with the use of the Gaussian method

Having compared the errors, we have the following function:

$$f(x) = a_1 \cdot e^{-\left(\frac{x-b_1}{c_1}\right)^2} + a_2 \cdot e^{-\left(\frac{x-b_2}{c_2}\right)^2} + a_3 \cdot e^{-\left(\frac{x-b_3}{c_3}\right)^2} + a_4 \cdot e^{-\left(\frac{x-b_4}{c_4}\right)^2} +$$
$$+ a_5 \cdot e^{-\left(\frac{x-b_5}{c_5}\right)^2} + a_6 \cdot e^{-\left(\frac{x-b_6}{c_6}\right)^2} + a_7 \cdot e^{-\left(\frac{x-b_7}{c_7}\right)^2} + a_8 \cdot e^{-\left(\frac{x-b_8}{c_8}\right)^2};$$

$$a_1 = 3{,}961\ (-0{,}772;\ 8{,}694);\ b_1 = 70{,}61\ (70{,}32;\ 70{,}9);\ c_1 = 0{,}39\ (-0{,}06;\ 0{,}84);$$
$$a_2 = 2{,}182\ (-0{,}265;\ 4{,}628);\ b_2 = 65{,}82\ (65{,}48;\ 66{,}17);\ c_2 = 0{,}704\ (0{,}07;\ 1{,}338);$$
$$a_3 = 5{,}435\ (-53{,}86;\ 64{,}73);\ b_3 = 63{,}2\ (57{,}87;\ 68{,}54);\ c_3 = 1{,}943\ (-4{,}613;\ 8{,}499);$$
$$a_4 = 75{,}3\ (16{,}3;\ 134{,}3);\ b_4 = 69{,}81\ (49;\ 90{,}61);\ c_4 = 10{,}52\ (-56{,}01;\ 77{,}04);$$
$$a_5 = 1{,}739\ (-7{,}113;\ 10{,}59);\ b_5 = 61{,}67(60{,}67;\ 62{,}68);\ c_5 = 0{,}448(-1{,}027;\ 1{,}924);$$
$$a_6 = 1{,}088(-6{,}998;\ 9{,}173);\ b_6 = 60{,}7(60{,}18;\ 61{,}22);\ c_6 = 0{,}291(-0{,}916;\ 1{,}497);$$
$$a_7 = -2{,}494(-161{,}4;\ 156{,}4);\ b_7 = 58{,}55(38{,}35;\ 78{,}75);\ c_7 = 0{,}817(-22{,}22;\ 23{,}86);$$
$$a_8 = 54{,}57(-668{,}5;\ 777{,}6);\ b_8 = 56{,}66(-16{,}93;\ 130{,}3);\ c_8 = 6{,}311(-65{,}52;\ 78{,}14).$$

The function of the dependence $G_{min} = f(A)$ defined with the use of the Gaussian method is shown in Figure 4.31.

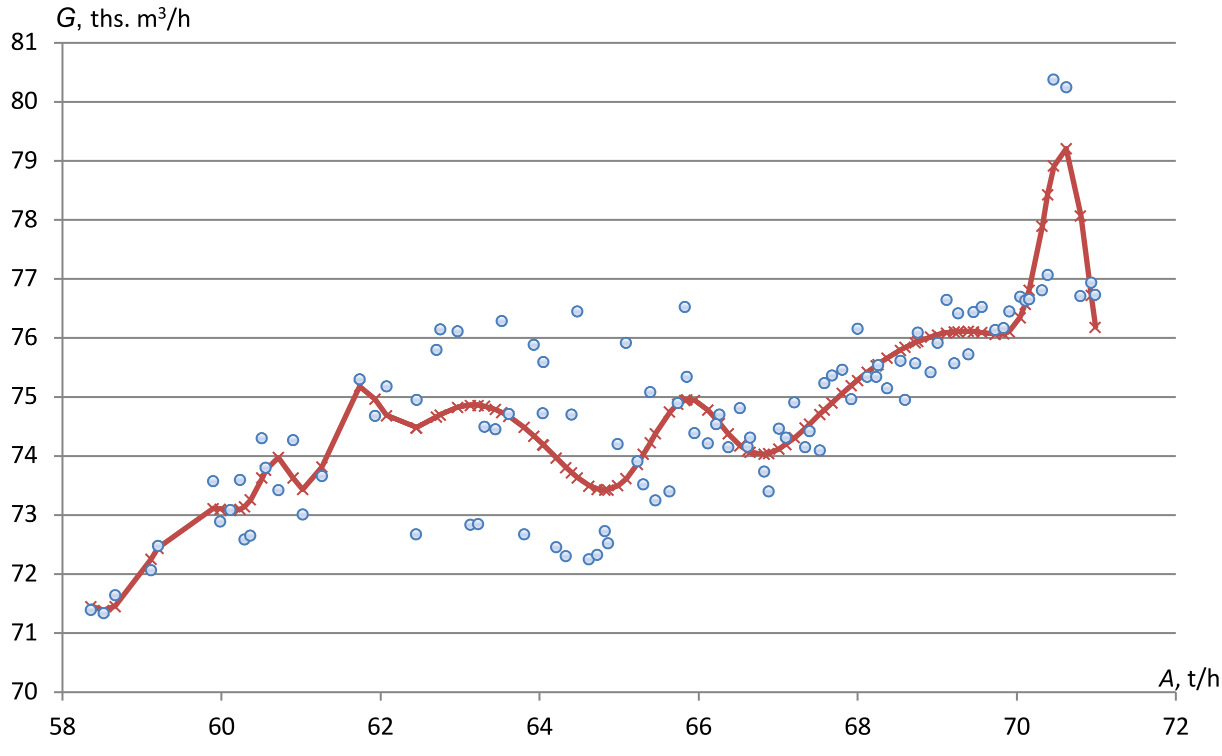


Figure 4.31 – The function of the dependence $G_{min} = f(A)$ defined with the use of the Gaussian method

Let us consider the dependence of natural gas consumption on ammonia production using the Rational method. In table 4.9, we present the types of dependences under study.

Table 4.9 – Type of dependences $G_{min} = f(A)$ using the Rational method

| No. | Rationals | |
|---|---|---|
| | Numerator | Denominator |
| 1 | Cubic polynomial | Linear polynomial |
| 2 | Cubic polynomial | Quadratic polynomial |
| 3 | Cubic polynomial | Cubic polynomial |
| 4 | Cubic polynomial | 4th degree polynomial |
| 5 | 4th degree polynomial | Linear polynomial |
| 6 | 4th degree polynomial | Quadratic polynomial |
| 7 | 4th degree polynomial | Cubic polynomial |
| 8 | 5th degree polynomial | Linear polynomial |
| 9 | 5th degree polynomial | Quadratic polynomial |
| 10 | 5th degree polynomial | Cubic polynomial |
| 11 | 5th degree polynomial | 4th degree polynomial |

Figure 4.32 shows a histogram with relative errors for the dependences $G_{min} = f(A)$ constructed with the use of the Rational method for functions of different types.

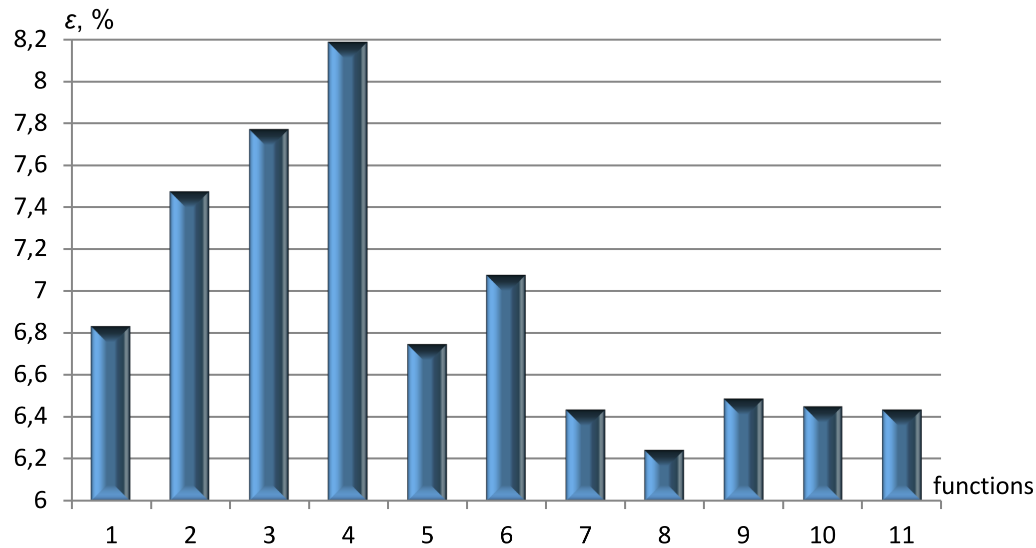

Figure 4.32 – Relative errors of the dependence $G_{min} = f(A)$ constructed with the use of the Rational method

Having compared the errors, we choose the following function:

$$f(x) = (p_1 \cdot x^5 + p_2 \cdot x^4 + p_3 \cdot x^3 + p_4 \cdot x^2 + p_5 \cdot x + p_6)/(x + q_1);$$

$$p_1 = 2{,}185 \cdot 10^{-4} \left(-0{,}732;\ 0{,}733\right);$$

$$p_2 = -4{,}202 \cdot 10^{-2} \left(-1{,}958 \cdot 10^5;\ 1{,}958 \cdot 10^5\right);$$

$$p_3 = 2{,}675\ \left(-3{,}788 \cdot 10^7;\ 3{,}788 \cdot 10^7\right);$$

$$p_4 = -55{,}14\ \left(-2{,}438 \cdot 10^9;\ 2{,}438 \cdot 10^9\right);$$

$$p_5 = -2{,}958\ \left(-5{,}194 \cdot 10^{10};\ 5{,}194 \cdot 10^{10}\right);$$

$$p_6 = 4{,}394 \cdot 10^{-2}\ \left(-4{,}885 \cdot 10^{10};\ 4{,}885 \cdot 10^{10}\right);$$

$$q_1 = 1{,}087\ \left(-8{,}974 \cdot 10^8;\ 8{,}974 \cdot 10^8\right).$$

The function of the dependence $G_{min} = f(A)$ defined with the use of the Rational method is shown in Figure 4.33.

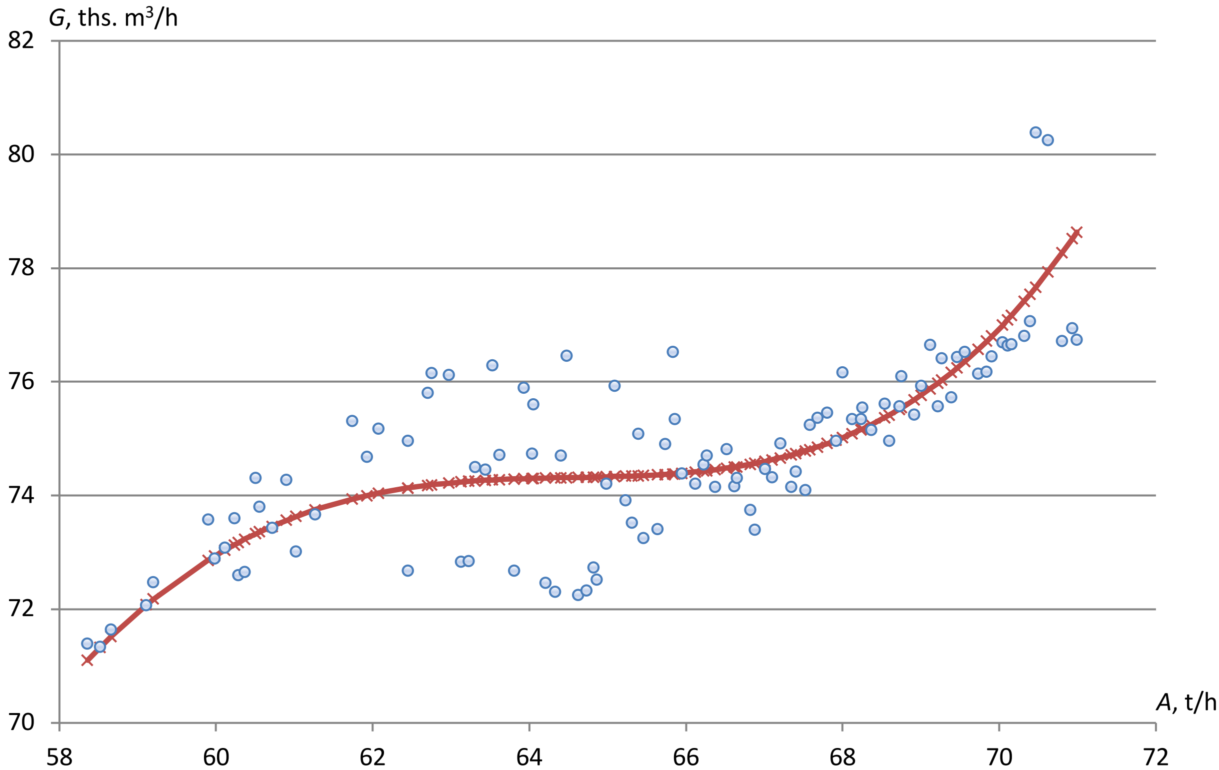


Figure 4.33 – The function of the dependence $G_{min} = f(A)$ defined with the use of the Rational method

Let us consider the dependence of natural gas consumption on ammonia production using the Sum of Sin Function method. In table 4.6, we present the types of dependences under study.

Figure 4.34 shows a histogram with relative errors for the dependences $G_{min} = f(A)$ constructed with the use of the Sum of Sin Function method for functions of different types.

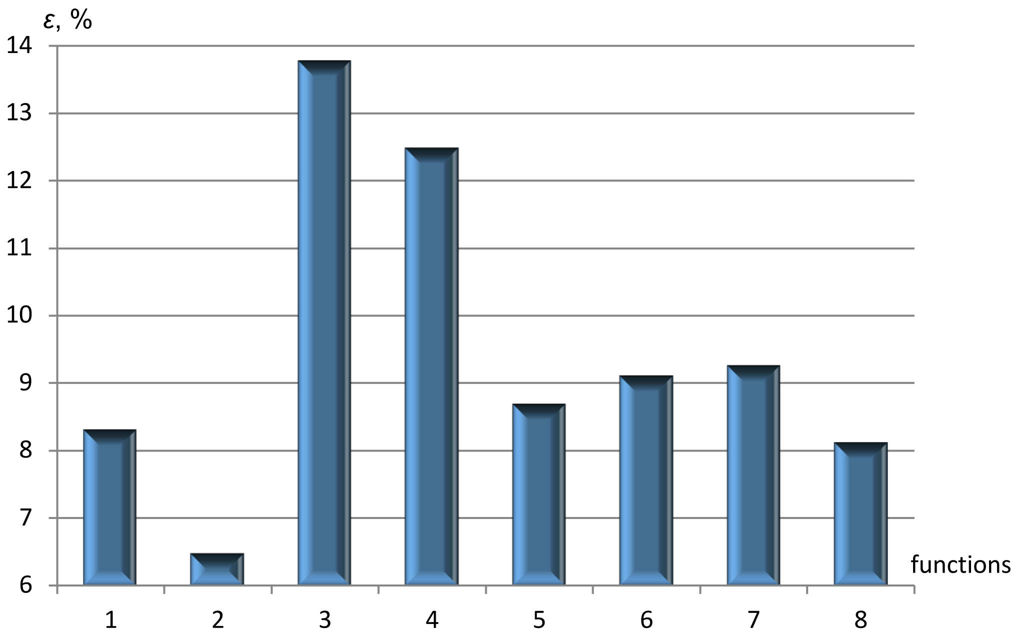


Figure 4.34 – Relative errors of the dependence $G_{min} = f(A)$ constructed with the use of the Sum of Sin Function method

Having compared the errors, we choose the following function:

$$f(x) = a_1 \cdot \sin(b_1 \cdot x + c_1) + a_2 \cdot \sin(b_2 \cdot x + c_2);$$
$$a_1 = 81,76\ (3,192;\ 160,3);$$
$$b_1 = 5,917 \cdot 10^{-2}\ (-0,206;\ 0,325);$$
$$c_1 = 10,04\ (-7,585;\ 27,66);$$
$$a_2 = 6,501\ (-73,71;\ 86,71);$$
$$b_2 = 0,29\ (-0,78;\ 1,359);$$
$$c_2 = 10,31\ (-60,86;\ 81,49).$$

The function of the dependence $G_{min} = f(A)$ defined with the use of the Sum of Sin Function method is shown in Figure 4.35.

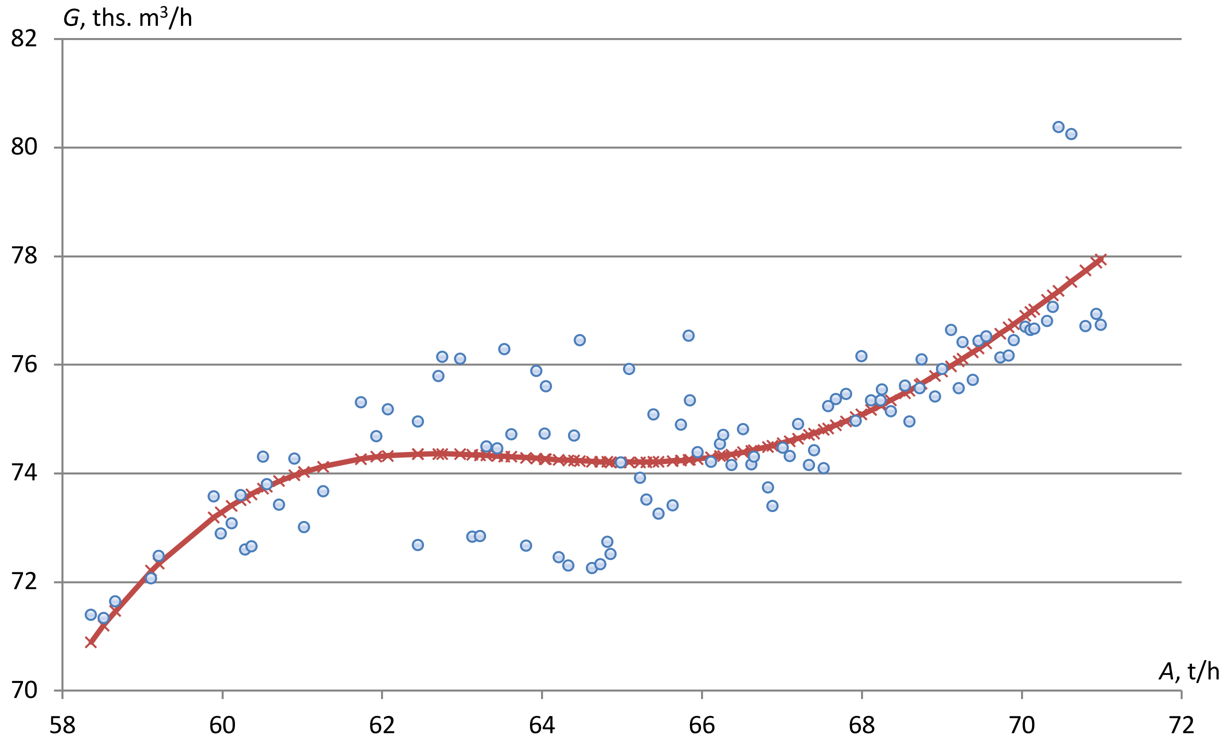


Figure 4.35 – The function of the dependence $G_{min} = f(A)$ constructed with the use of the Sum of Sin Function method

Having compared various types of functions within each method, we choose the dependence with the minimal relative error (see Figure 4.36) and graphically present the results in Figure 4.37.

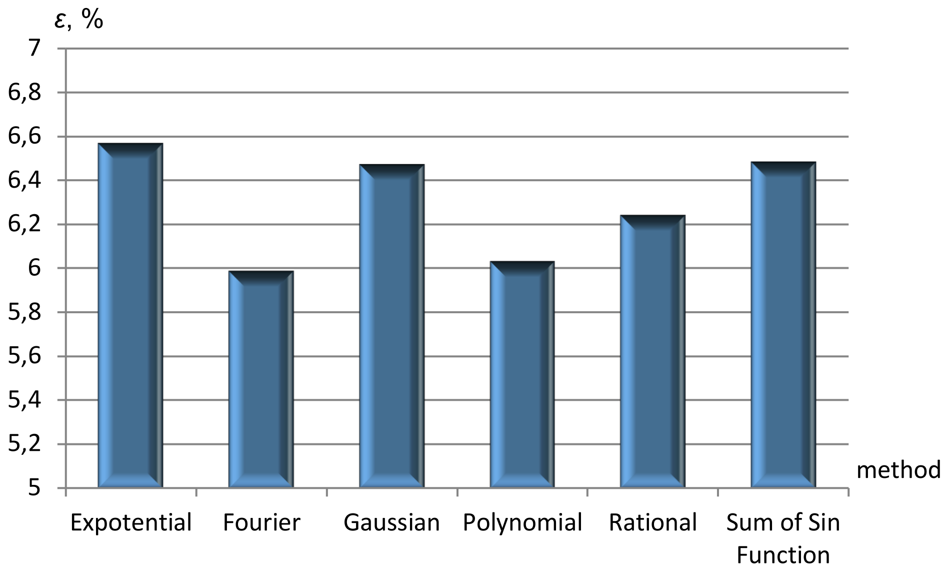


Table 4.36 – Type of functions with minimal relative errors

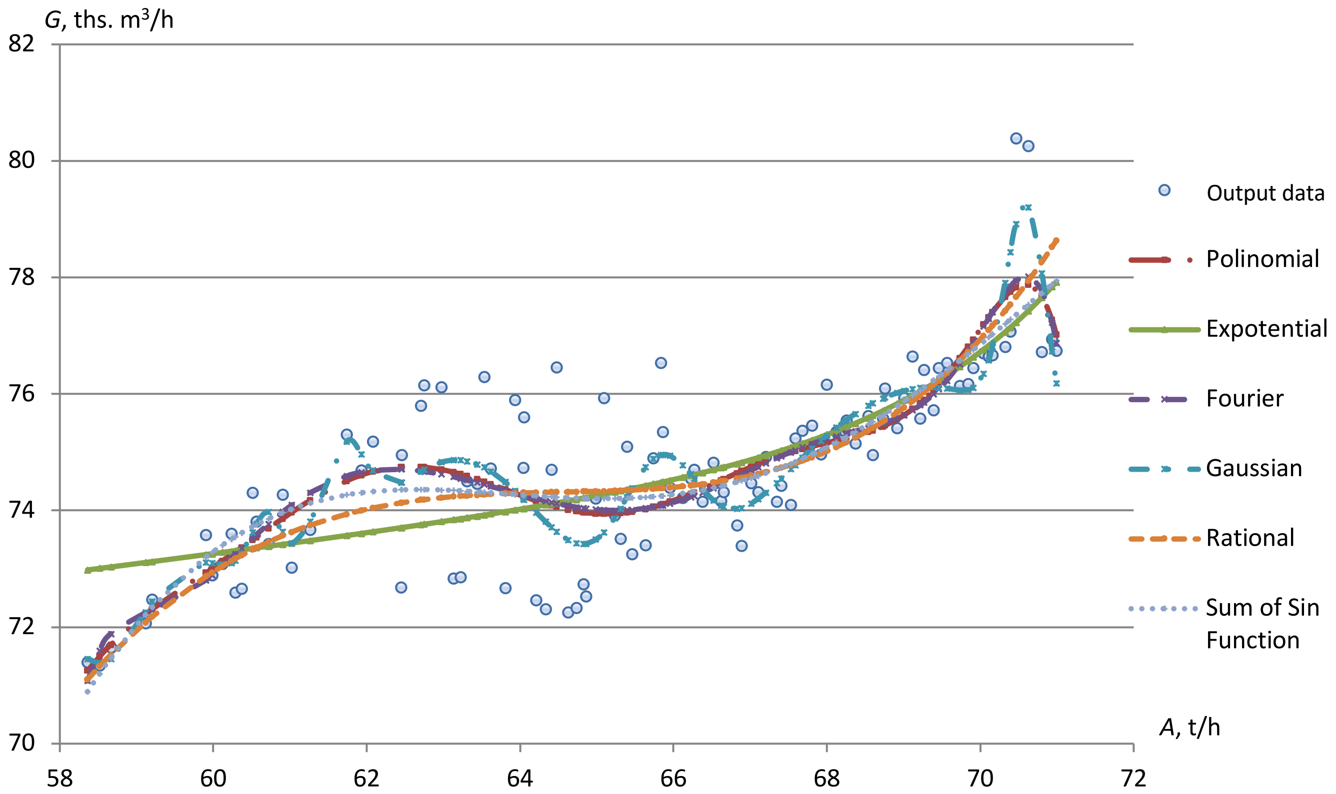


Figure 4.37 – Dependences of natural gas consumption on ammonia production

Considering the dependence of natural gas consumption on ammonia production, it was found that the Sum of Sin Function method gives the best result for data recovery. Such a conclusion can be made due to the fact that in this method there is the smallest relative error of data recovery in comparison with other methods.

### 4.2.3 Construction of the dependence of used power on natural gas consumption

Let us consider the dependence of used power on natural gas consumption. Using the Curve Fitting Toolbox, we find the dependency functions with the application of the Polynomial method.

Figure 4.38 shows a histogram with relative errors for the dependences $P = f(G)$ constructed with the use of the Polynomial method for functions of different types.

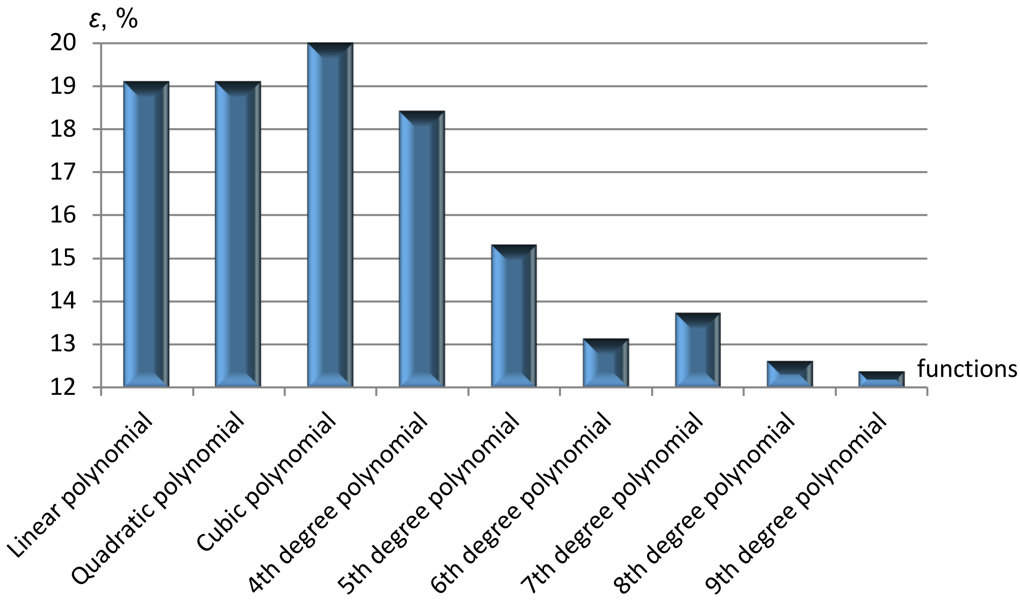


Figure 4.38 – Relative errors of the dependence $P = f(G)$ constructed with the use of the Polynomial method

Having compared the errors, we choose the dependence with the minimum value, i.e., it is the dependence on the polynomial of the ninth degree, namely:

$$f(x) = p_1 \cdot x^9 + p_2 \cdot x^8 + p_3 \cdot x^7 + p_4 \cdot x^6 + p_5 \cdot x^5 + p_6 \cdot x^4 + p_7 \cdot x^3 + p_8 \cdot x^2 + p_9 \cdot x + p_{10};$$

$$p_1 = -4,544 \cdot 10^{-3}\ \left(-8,52 \cdot 10^{-3};\ -5,682 \cdot 10^{-4}\right);\ p_2 = 3,116\ \left(0,378;\ 5,853\right);$$

$$p_3 = -949,1\left(-1787;\ -111,7\right);\ p_4 = 1,686 \cdot 10^5\left(1,92 \cdot 10^4;\ 3,18 \cdot 10^5\right);$$

$$p_5 = -1,925 \cdot 10^7\left(-3,638 \cdot 10^7;\ -2,118 \cdot 10^6\right);\ p_6 = 1,465 \cdot 10^9\left(1,554 \cdot 10^8;\ 2,774 \cdot 10^9\right);$$

$$p_7 = -7,427 \cdot 10^{10}\left(-1,41 \cdot 10^{11};\ -7,587 \cdot 10^9\right);\ p_8 = 2,421 \cdot 10^{12}\left(2,375 \cdot 10^{11};\ 4,604 \cdot 10^{12}\right);$$

$$p_9 = -4,6 \cdot 10^{13}\left(-8,768 \cdot 10^{13};\ -4,324 \cdot 10^{12}\right);\ p_{10} = 3,885 \cdot 10^{14}\left(3,489 \cdot 10^{13};\ 7,42 \cdot 10^{14}\right).$$

The function of the dependence $P = f(G)$ defined with the use of the Polynomial method is shown in Figure 4.39.

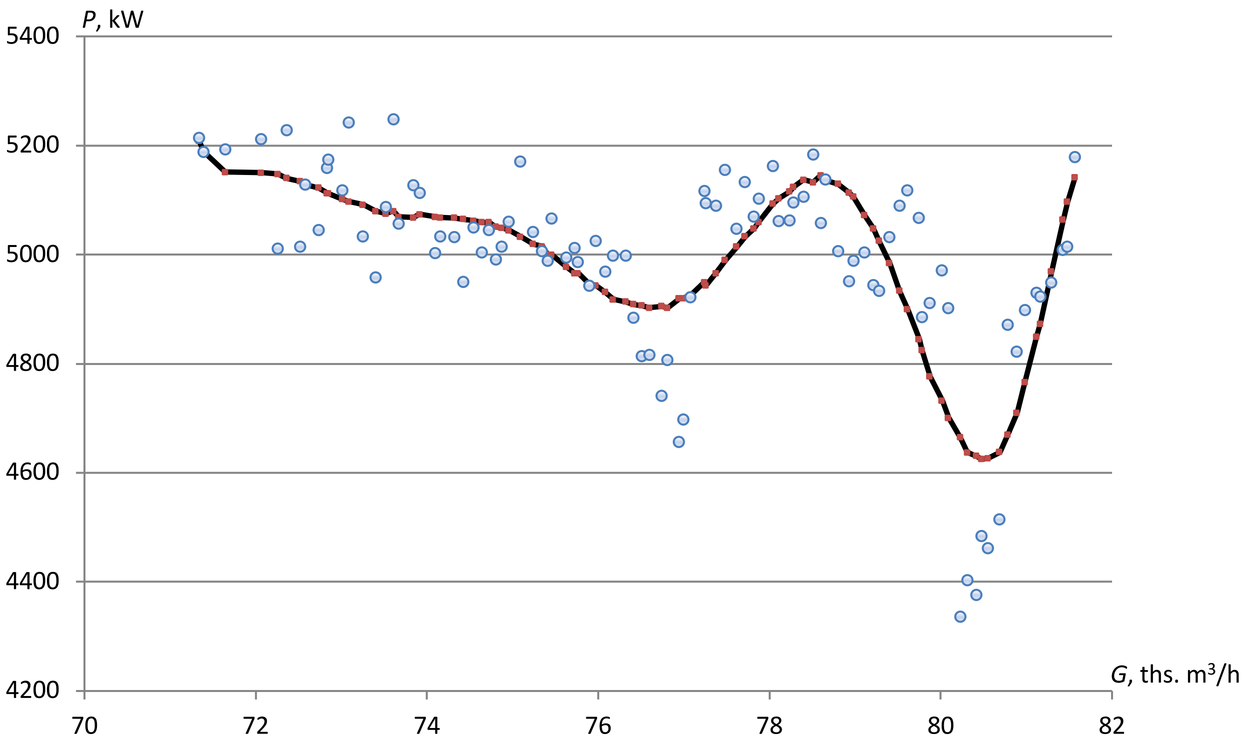


Figure 4.39 – The function of the dependence $P = f(G)$ constructed with the use of the Polynomial method

Let us consider the dependences using the Exponential method. In Table 4.10, we present relative errors for the dependence $P = f(G)$.

Table 4.10 – Relative errors of the dependence $P = f(G)$ constructed with the use of the Exponential method

| Exponentials | $\varepsilon$, % |
|---|---|
| $ae^{(bx)}$ | 19.085 |
| $ae^{(bx)} + ce^{(dx)}$ | 19.219 |

Having compared the errors, we choose the dependence in which it turned out to be minimal, namely:

$$f(x) = ae^{(bx)};$$
$$a = 8005(6573,\ 9436);$$
$$b = -6{,}158 \cdot 10^{-3}\left(-8{,}488 \cdot 10^{-3};\ -3{,}828 \cdot 10^{-3}\right).$$

The function of the dependence P = f(G) defined with the use of the Exponential method is shown in Figure 4.40.

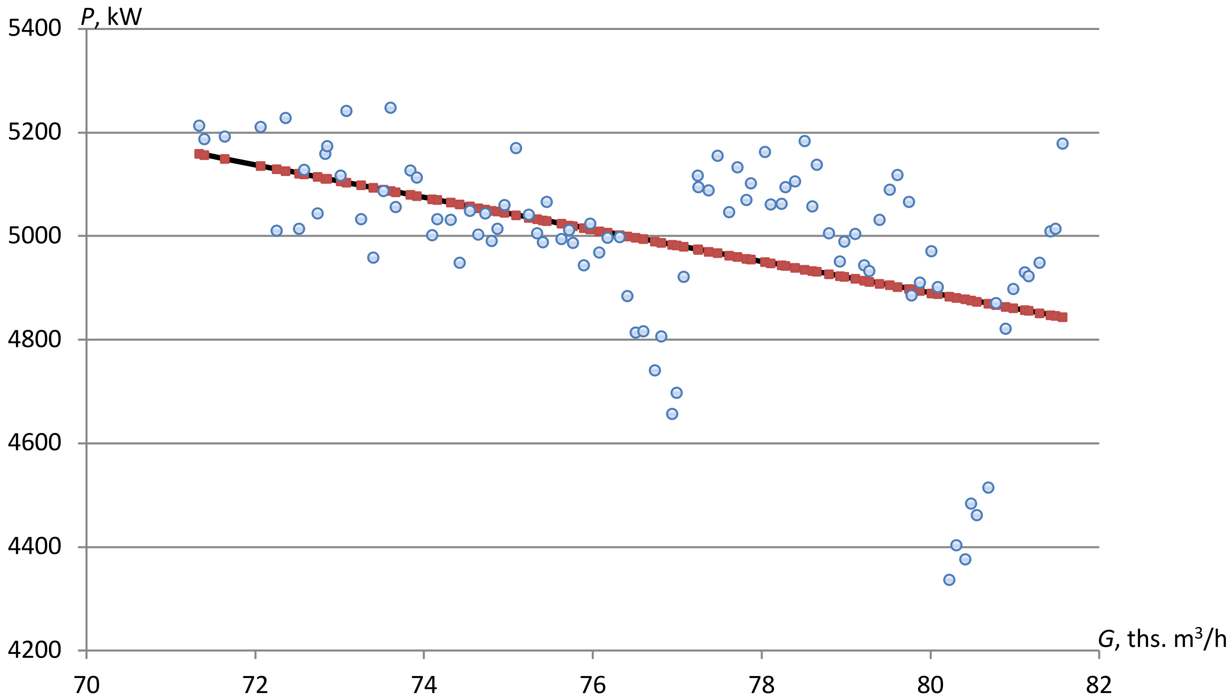


Figure 4.40 – The function of the dependence $P = f(G)$ constructed with the use of the Exponential method

Let us consider the dependence $P = f(G)$ using the Fourier method. In table 4.3, we present the types of dependences under study.

Figure 4.41 shows a histogram with relative errors for the dependences $P = f(G)$ constructed with the use of the Fourier method for functions of different types.

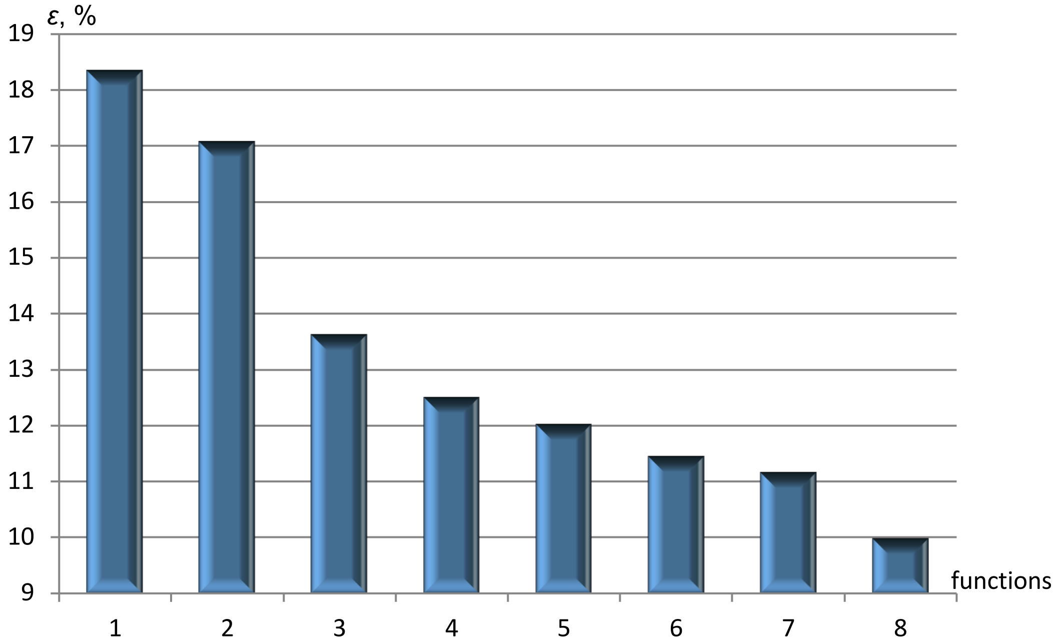


Figure 4.41 – Relative errors of the dependence $P = f(G)$ constructed with the use of the Fourier method

Having compared the errors, we have the following function:

$$f(x)=a_0+a_1\cdot\cos(x\cdot w)+b_1\cdot\sin(x\cdot w)+a_2\cdot\cos(2\cdot x\cdot w)+b_2\cdot\sin(2\cdot x\cdot w)+a_3\cdot\cos(3\cdot x\cdot w)+$$
$$+b_3\cdot\sin(3\cdot x\cdot w)+a_4\cdot\cos(4\cdot x\cdot w)+b_4\cdot\sin(4\cdot x\cdot w)+a_5\cdot\cos(5\cdot x\cdot w)+b_5\cdot\sin(5\cdot x\cdot w)+$$
$$+a_6\cdot\cos(6\cdot x\cdot w)+b_6\cdot\sin(6\cdot x\cdot w)+a_7\cdot\cos(7\cdot x\cdot w)+b_7\cdot\sin(7\cdot x\cdot w)+$$
$$+a_8\cdot\cos(8\cdot x\cdot w)+b_8\cdot\sin(8\cdot x\cdot w);$$

$a_0$ = 3,274·10$^7$ (-2,309·10$^8$; 2,964·10$^8$);
$a_1$ = 3,646·10$^7$ (-1,654·10$^8$; 2,383·10$^8$);
$b_1$ = -4,767·10$^7$ (-8,051·10$^8$; 7,098·10$^8$);
$a_2$ = -1,212·10$^7$ (-1,025·10$^9$; 1·10$^9$);
$b_2$ = -4,448·10$^7$ (-1,514·10$^8$; 6,241·10$^7$);
$a_3$ = -2,725·10$^7$ (-5,789·10$^8$; 5,244·10$^8$);
$b_3$ = -1,1·10$^7$ (-7,681·10$^8$; 7,461·10$^8$);
$a_4$ = -1,309·10$^7$ (-2,387·10$^8$; 2,125·10$^8$);
$b_4$ = 7,862·10$^6$ (-5,908·10$^8$; 6,065·10$^8$);
$a_5$ = -6,218·10$^5$ (-3,173·10$^8$; 3,16·10$^8$);
$b_5$ = 6,234·10$^6$ (-7,116·10$^7$; 8,362·10$^7$);
$a_6$ = 1,431·10$^6$ (-8,779·10$^7$; 9,065·10$^7$);
$b_6$ = 1,284·10$^6$ (-7,834·10$^7$; 8,091·10$^7$);
$a_7$ = 3,864·10$^5$ (-3,418·10$^6$; 4,19·10$^6$);
$b_7$ = -8,722·10$^4$ (-2,851·10$^7$; 2,834·10$^7$);
$a_8$ = 1,506·10$^4$ (-3,087·10$^6$; 3,117·10$^6$);
$b_8$ = -3,875·10$^4$ (-1,508·10$^6$; 1,43·10$^6$);
$w$ = 0,276 (0,142; 0,411).

The function of the dependence $P = f(G)$ defined with the use of the Fourier method is shown in Figure 4.42.

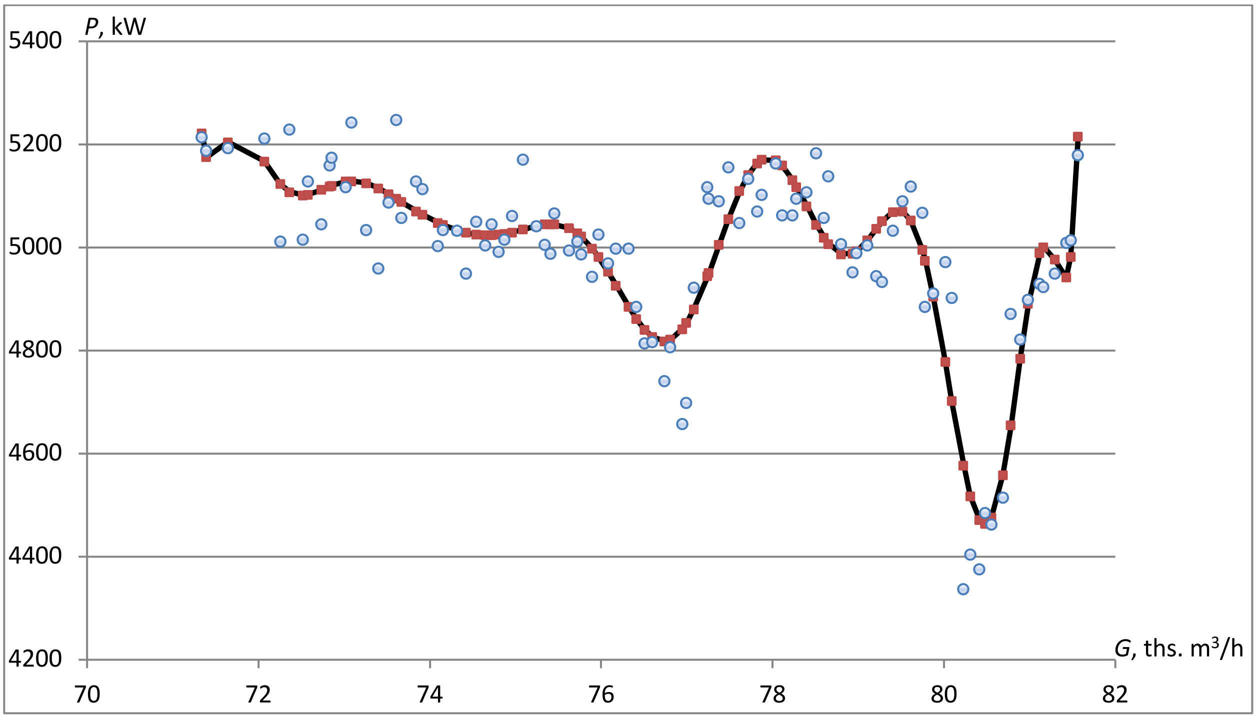


Figure 4.42 – The function of the dependence $P = f(G)$ constructed with the use of the Fourier method

Let us consider the dependence of used power on natural gas consumption using the Gaussian method. In table 4.4, we present the types of dependences under study.

Figure 4.45 shows a histogram with relative errors for the dependences $P = f(G)$ constructed with the use of the Gaussian method for functions of different types.

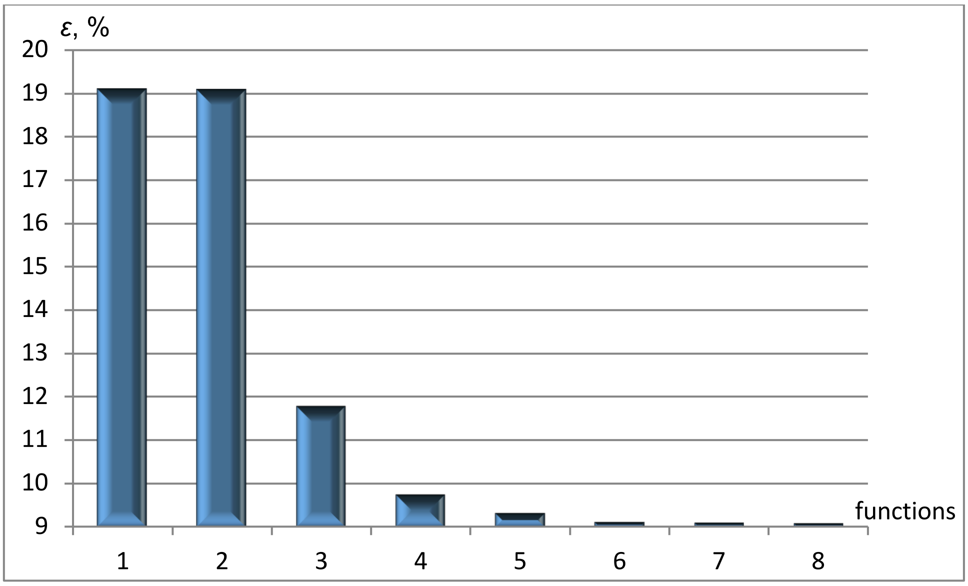


Figure 4.45 – Relative errors of the dependence $P = f(G)$ constructed with the use of the Gaussian method

Having compared the errors, we choose the following function:

$$f(x) = a_1 \cdot e^{-\left(\frac{x-b_1}{c_1}\right)^2} + a_2 \cdot e^{-\left(\frac{x-b_2}{c_2}\right)^2} + a_3 \cdot e^{-\left(\frac{x-b_3}{c_3}\right)^2} + a_4 \cdot e^{-\left(\frac{x-b_4}{c_4}\right)^2} +$$

$$+ a_5 \cdot e^{-\left(\frac{x-b_5}{c_5}\right)^2} + a_6 \cdot e^{-\left(\frac{x-b_6}{c_6}\right)^2} + a_7 \cdot e^{-\left(\frac{x-b_7}{c_7}\right)^2} + a_8 \cdot e^{-\left(\frac{x-b_8}{c_8}\right)^2};$$

$a_1$ = 5117 (5024; 5209); $b_1$ = 73,24 (71,13; 75,35); $c_1$ = 7,188 (-9,318; 23,69);

$a_2$ = 2105 (-3878; 8088); $b_2$ = 78,66 (77,97; 79,35); $c_2$ = 1,459 (-0,599; 3,517);

$a_3$ = 3680 (-3320; $1{,}068 \cdot 10^4$); $b_3$ = 81,64 (81,34; 81,93); $c_3$ = 1,53 (0,323; 2,737);

$a_4$ = 439.3 (-2290; 3168); $b_4$ = 71,18 (68,44; 73,92); $c_4$ = 0,897 (-2,114; 3,909);

$a_5$ = 477.9 (-430.3; 1386); $b_5$ = 77,37 (77,23; 77,51); $c_5$ = 0,407 (0,048; 0,7662);

$a_6$ = 544.8 (-992.3; 2082); $b_6$ = 76,22 (75,81; 76,64); $c_6$ = 0,629 (-0,096; 1,353);

$a_7$ = 801.3 (-58.34; 1661); $b_7$ = 79,75 (79,66; 79,84); $c_7$ = 0,495 (0,246; 0,743);

$a_8$ = 280.4 (-425.2; 985.9); $b_8$ = 75,22 (74,72; 75,73); $c_8$ = 0,521 (-0,197; 1,239).

The function of the dependence $P = f(G)$ defined with the use of the Gaussian method is shown in Figure 4.46.

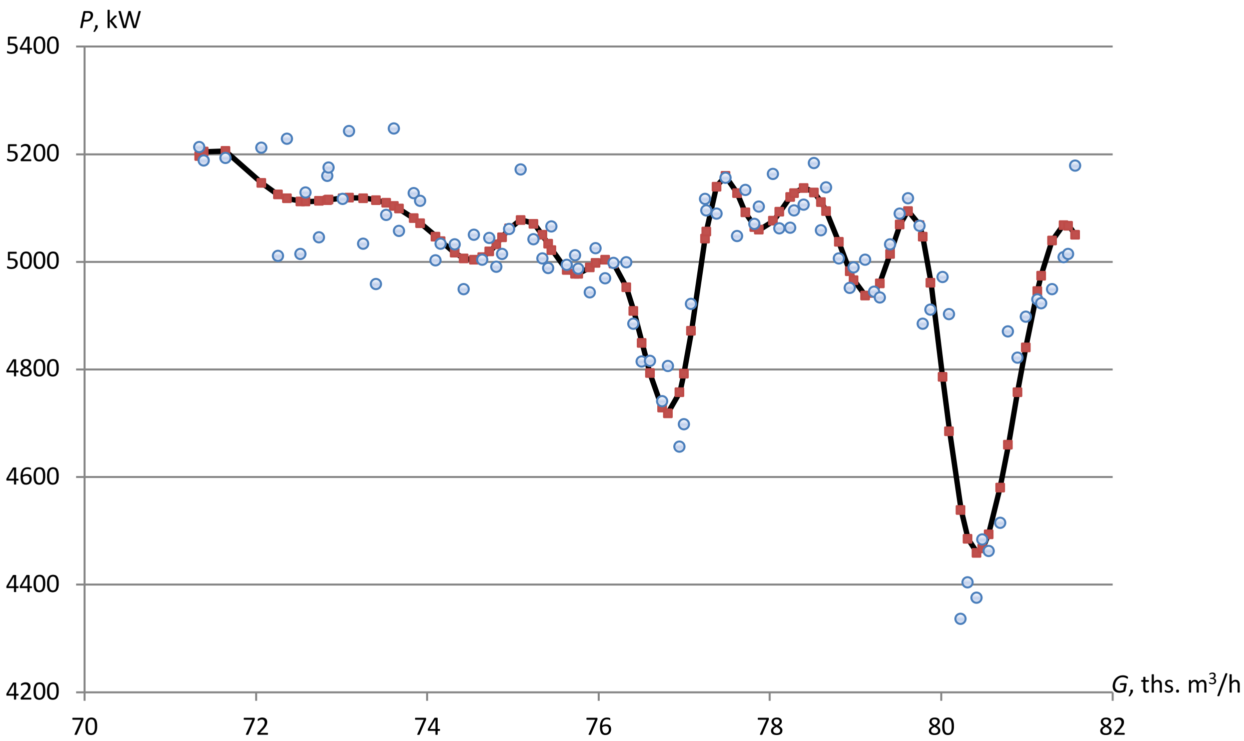


Figure 4.46 – The function of the dependence $P = f(G)$ constructed with the use of the Gaussian method

Let us consider the dependence of used power on natural gas consumption using the Rational method. In table 4.11, we present the types of dependences under study.

Table 4.11 – Types of dependences $P = f(G)$ constructed with the use of the Rational method

| No. | Rationals | |
|---|---|---|
| | Numerator | Denominator |
| 1 | Quadratic polynomial | Linear polynomial |
| 2 | Cubic polynomial | Quadratic polynomial |
| 3 | 4th degree polynomial | Linear polynomial |
| 4 | 4th degree polynomial | Quadratic polynomial |
| 5 | 4th degree polynomial | Cubic polynomial |
| 6 | 5th degree polynomial | Linear polynomial |
| 7 | 5th degree polynomial | Quadratic polynomial |
| 8 | 5th degree polynomial | Cubic polynomial |
| 9 | 5th degree polynomial | 4th degree polynomial |

Figure 4.47 shows a histogram with relative errors for the dependences $P = f(G)$ constructed with the use of the Rational method for functions of different types.

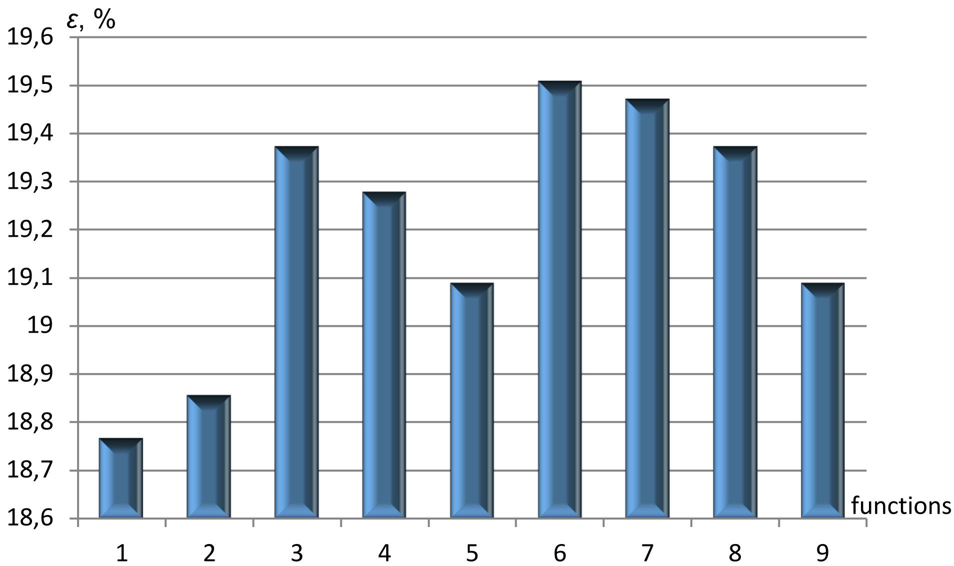


Figure 4.47 – Relative errors of the dependence $P = f(G)$ constructed with the use of the Rational method

Having compared the errors, we have the following function:

$$f(x) = (p_1 \cdot x^2 + p_2 \cdot x + p_3) / (x + q_1);$$
$$p_1 = 23{,}09 \quad (-1154;\ 1200);$$
$$p_2 = 640 \quad (-1{,}971 \cdot 10^5;\ 1{,}984 \cdot 10^5);$$
$$p_3 = -4{,}887 \cdot 10^4 \quad (-1{,}115 \cdot 10^7;\ 1{,}105 \cdot 10^7);$$
$$q_1 = -49{,}36 \quad (-625{,}1;\ 526{,}4).$$

The function of the dependence $P = f(G)$ defined with the use of the Rational method is shown in Figure 4.48.

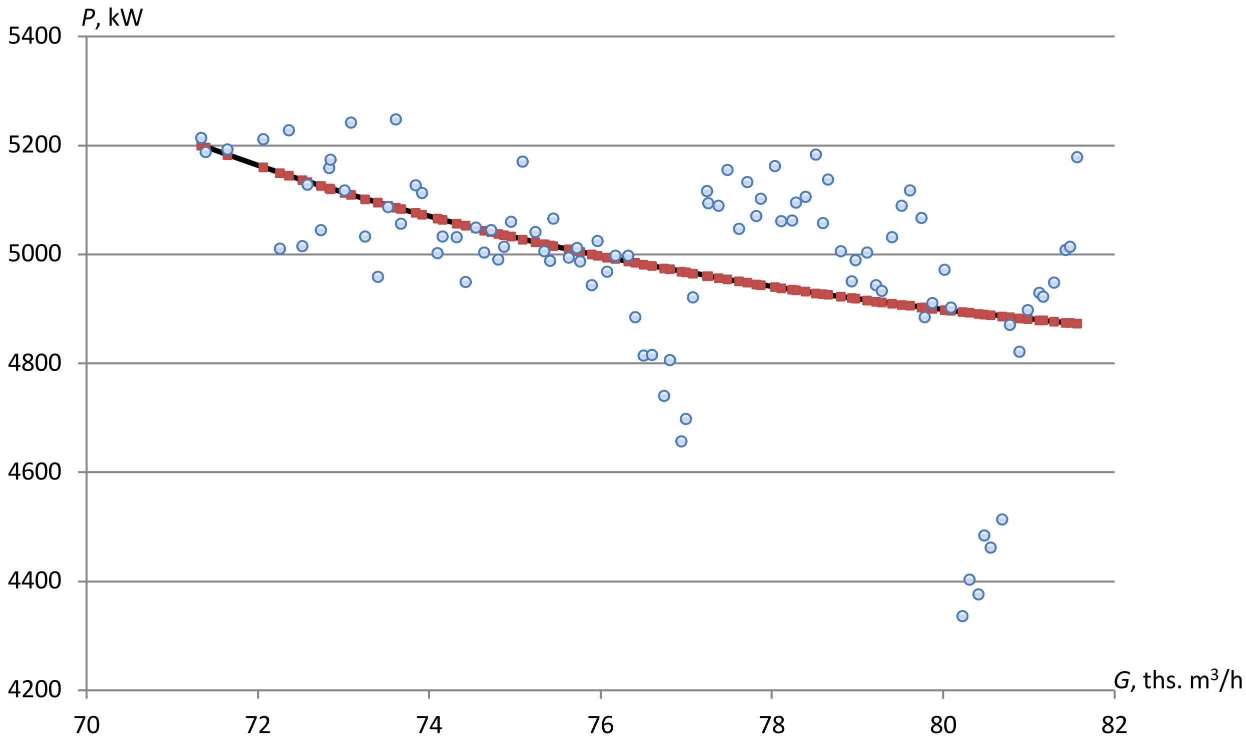


Figure 4.48 – The function of the dependence $P = f(G)$ constructed with the use of the Rational method

Let us consider the dependence of used power on natural gas consumption using the Sum of Sin Function method. In table 4.6, we present the types of dependences under study.

Figure 4.49 shows a histogram with relative errors for the dependences $P = f(G)$ constructed with the use of the Sum of Sin Function method for functions of different types.

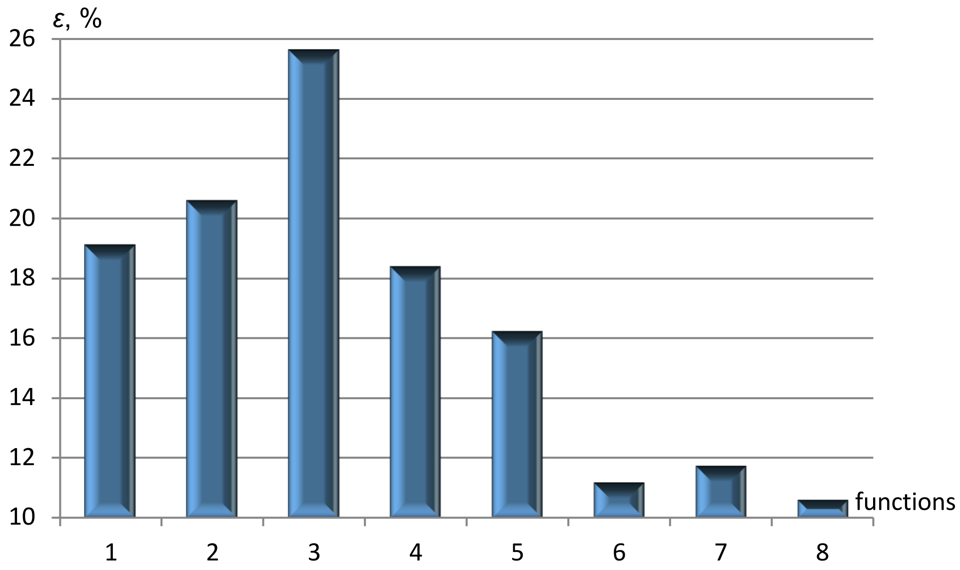


Figure 4.49 – Relative errors of the dependence $P = f(G)$ constructed with the use of the Sum of Sin Function method

Having compared the errors, we have the following function:

$$f(x) = a_1 \cdot \sin(b_1 \cdot x + c_1) + a_2 \cdot \sin(b_2 \cdot x + c_2) +$$
$$+ a_3 \cdot \sin(b_3 \cdot x + c_3) + a_4 \cdot \sin(b_4 \cdot x + c_4) + a_5 \cdot \sin(b_5 \cdot x + c_5) +$$
$$+ a_6 \cdot \sin(b_6 \cdot x + c_6) + a_7 \cdot \sin(b_7 \cdot x + c_7) + a_8 \cdot \sin(b_8 \cdot x + c_8);$$

| | | |
|---|---|---|
| $a_1$ =8150 (-5,56·10$^7$; 5,562·10$^7$); | $b_1$ =0,299 (-1075; 1076); | $c_1$ =-2,445 (-8,241·10$^4$; 8,241·10$^4$); |
| $a_2$ =3547 (-5,487·10$^7$; 5,488·10$^7$); | $b_2$ =0,566 (-2094; 2095); | $c_2$ =5,414 (-1,604·10$^5$; 1,604·10$^5$); |
| $a_3$ =571,2 (-1,224·10$^6$; 1,225·10$^6$); | $b_3$ =1,216 (-1754; 1756); | $c_3$ =2,537 (-1,345·10$^5$; 1,345·10$^5$); |
| $a_4$ =329,2 (-1,557·10$^6$; 1,557·10$^6$); | $b_4$ =1,721 (-1058; 1062); | $c_4$ =11,06 (-8,108·10$^4$; 8,11·10$^4$); |
| $a_5$ =189,8 (-3,716·10$^4$; 3,754·10$^4$); | $b_5$ =3,147 (-58,06; 64,36); | $c_5$ =-3,644 (-4671; 4664); |
| $a_6$ =106,2 (-6,977·10$^4$; 6,998·10$^4$); | $b_6$ =2,578 (-286,2; 291,3); | $c_6$ = -7,194 (-2,207·10$^4$; 2,205·10$^4$); |
| $a_7$ =110,3 (-8246; 8467); | $b_7$ =3,672 (-9; 16,35); | $c_7$ =3,776 (-955,6; 963,2); |
| $a_8$ =64,1 (28,34; 99,86); | $b_8$ =5,495 (5,156; 5,833); | $c_8$ =3,665 (-22,18; 29,51); |

The function of the dependence $P = f(G)$ defined with the use of the Sum of Sin Function method is shown in Figure 4.50.

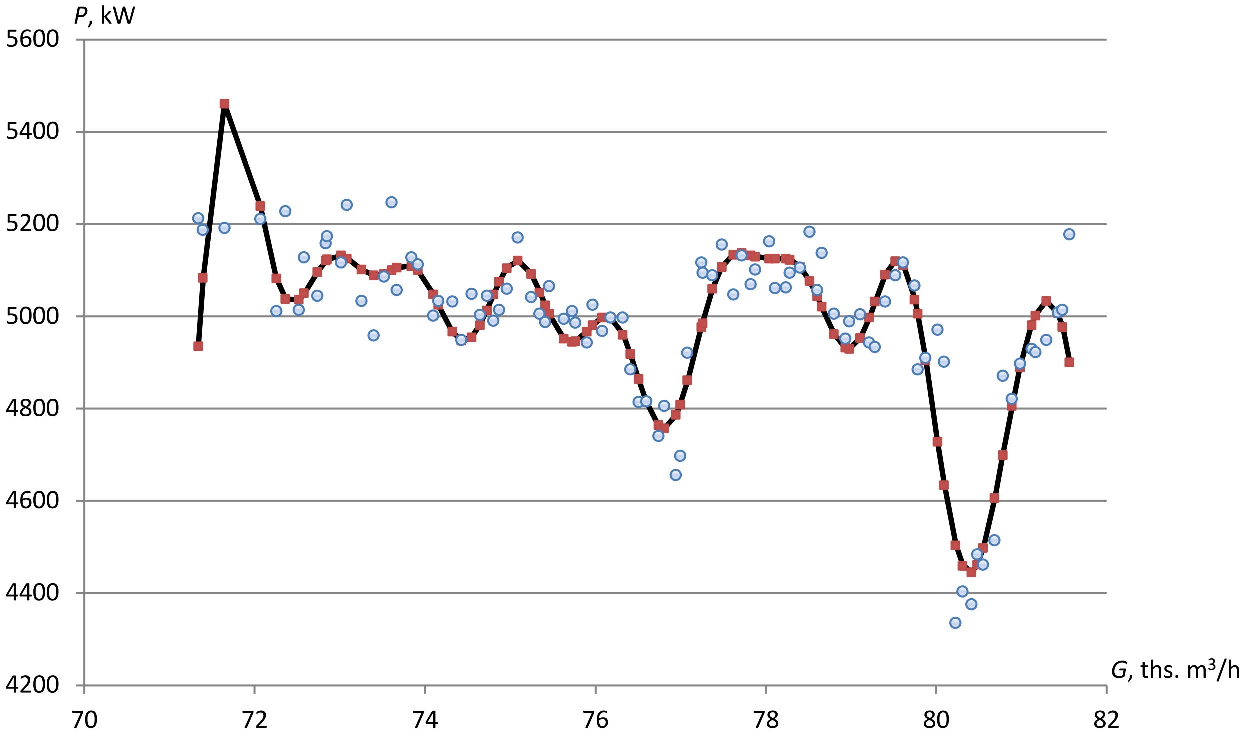


Figure 4.50 – The function of the dependence $P = f(G)$ constructed with the use of the Sum of Sin Function method

Having compared various types of functions within each method, we choose the dependence with the minimal relative error (see Figure 4.51) and graphically present the results in Figure 4.52.

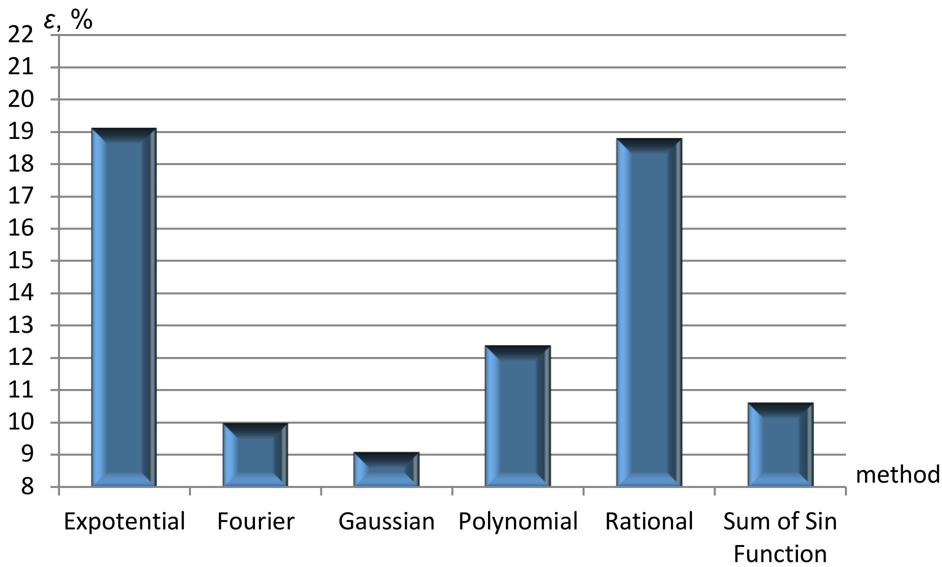


Table 4.51 – Type of functions with minimal relative errors

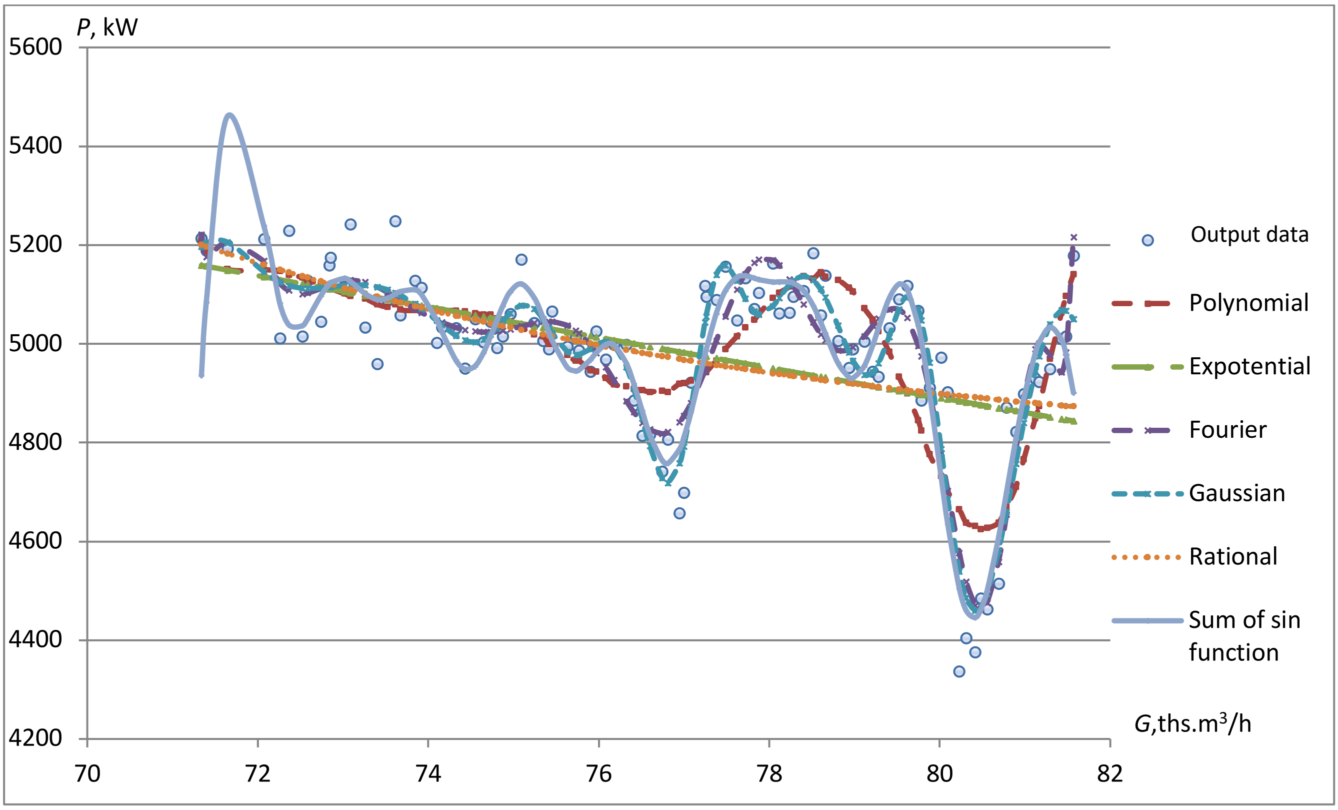


Figure 4.52 – Dependences of power consumption on natural gas consumption

Considering the dependence of power used on natural gas consumption, it was found that the Rational method gives the best result for data recovery. Such a conclusion can be made due to the fact that in this method there is the smallest relative error of data recovery in comparison with other methods.

### 4.2.4 Analysis of the obtained results

Total consumed power during the summer period is 416.67 MW. Using the Sum of Sin Function method, the value of the used power was found as a dependence on the ammonia production during the summer period. After summarizing all the values, we got 408.8 MW. The relative error for predicting missing data is 1.89 %.

The systematization of computational results is proposed as follows. Initially, the number of interrelated accounting values is determined, in our case, the gas and electricity consumed and the capacity of ammonia production. For further construction these values divide the circular diagram into sectors in which all relative errors are displayed sequentially in the form of vectors for different methods.

Vectors from each sector are interconnected, forming triangles. A triangle with a minimum area determines the types of methods with minimum values of relative errors. In practice, it is advisable to compare figures with a minimum area and formed from vectors of one method. In this case, with a slight difference, in order to simplify mathematical calculations, one method should be used to identify the relationships between all the constituents.

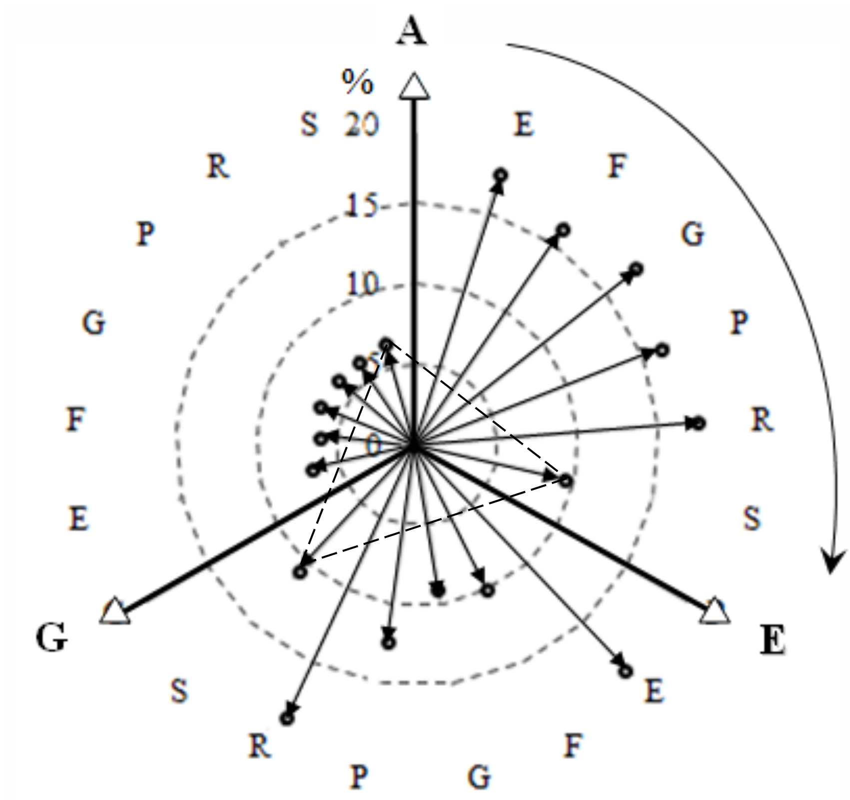


Figure 4.53 – Relative error values used for methods for establishing the relationship between **A** – ammonia, **E** – electric energy, and **G** – gas: E – Exponential, F – Fourier, G – Gaussian, P – Polynomial, R – Rational, and S – Sum of Sin Function

According to Figure 4.53, any of the methods considered may be used to determine the amount of natural gas consumed for the production of a given volume of ammonia as the proportions of their relative error values are calculated.

In the case of recovery of lost values of electricity consumption from natural gas consumed, it is necessary to use dependences obtained with the use of the Fourier, Gaussian, Polynomial and Sum of Sin Function methods.

The establishment of dependencies between the considered values of consumption and production is determined by the connection between electricity and ammonia, in this case, it is advisable to use the Sum of Sin Function method.

### 4.2.5 Economic efficiency of data recovery

Economic efficiency was estimated due to the comparison of payments for electricity using the methods applying by power supply organizations, and global data recovery methods.

In the summer period, data at the enterprise were lost in 3 days and 8 hours, starting at midnight on the first day.

The enterprise pays the power supply organization for the consumed electric energy at a three-zone tariff. According to the decree [3] in order to calculate the consumers' tariffs for electric energy, differentiated according to periods of time are set in the Table 4.12.

Table 4.12 - Accounting by three zones

| | May – August | Tariff coefficient |
|---|---|---|
| Peak | from 8:00 AM to 11:00 AM<br>from 8:00 PM to 11:00 PM | 1.68 |
| Intermediate | from 7:00 AM to 8:00 AM | 1.02 |

| | | |
|---|---|---|
| (half-peak) | from 11:00 AM to 8:00 PM<br>from 11:00 PM to 12:00 AM | |
| Night | from 12:00 AM to 7:00 AM | 0.35 |

At the enterprise, there was a loss in data on electricity accounting (not due to the fault of the consumer). The amount of electricity consumed by the consumer from the date of the failure to the day of recovery of the settlement accounting is determined by the supplier of electric energy on the basis of technical (control) accounting devices or calculated on the daily average volume of electricity consumption. In this case, the previous or next calculation period before (after) the failure of settlement accounting is taken into account.

According to [2], the start date of the accounting failure period is considered to be the first day of the current accounting period in which the accounting failure was detected, or the time and day recorded by the accounting device (automated accounting system).

The settlement period used to determine the daily average electricity supply is determined by agreement of the parties [2].

Based on data available, a settlement was made on the daily average electricity consumption for the previous calculation period.

It was agreed that the settlement period is 10 days. On the basis of which the arithmetic average of the hourly values of electricity consumption during the previous days was found. The daily average power and power found using global methods are shown in Figure 4.54.

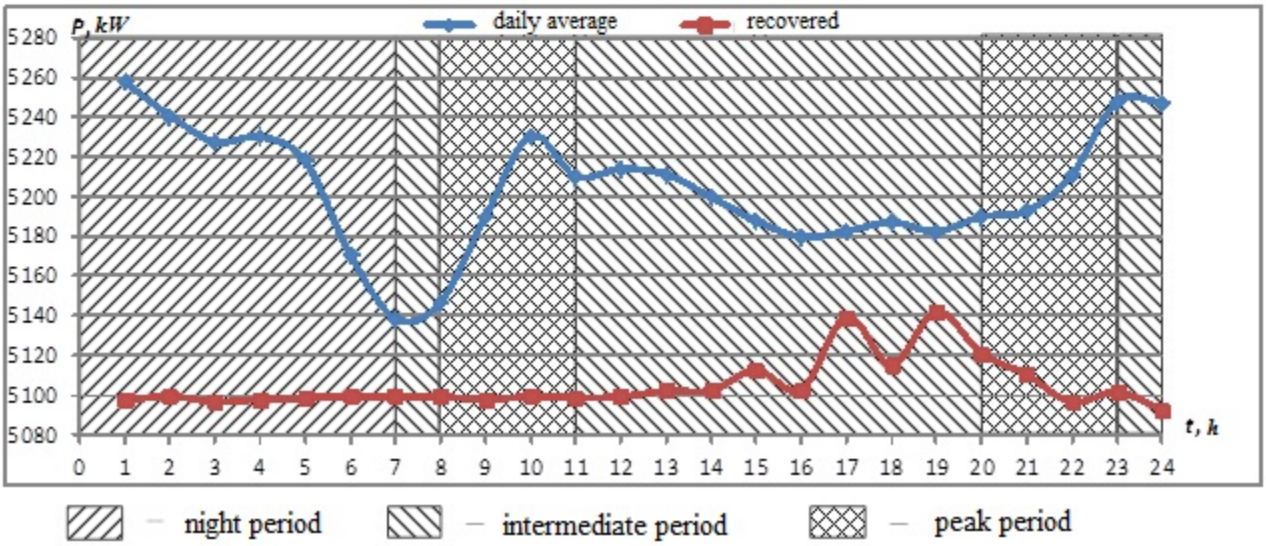


Figure 4.54 - Daily average hourly power values

Calculation of electricity was carried out according to the formula:

$$W = \sum_{i=1}^{3} k_i P_i ,$$

where $k$ – coefficient of the corresponding zone of the day;

$P$ - power per hour in the corresponding zone of the day.

In case of unrecovered accounting data, the enterprise paid for the consumed electricity:

$$W_1 = 5257{,}394 \cdot 0{,}35 + ... + 5146{,}729 \cdot 1{,}02 = 388796{,}94 \text{ UAH}$$

Substituting the recovered data calculated by the Fourier method, we have:

$$W_2 = 5097{,}528 \cdot 0{,}35 + ... + 5097{,}54 \cdot 1{,}02 = 382060{,}88 \text{ UAH}$$

As a result, we got savings of 6736.06 UAH according to the global method of restored data in comparison with daily average values of electric energy consumption.

This calculation shows that in the absence of data on electricity consumption it is more profitable for the enterprise to use this method of data recovery and to pay for it.

# 5 OCCUPATIONAL HEALTH AND SAFETY IN EMERGENCY SITUATIONS DURING THE PC OPERATION AND THE TRANSFER OF INFORMATION

## 5.1 Analysis of working conditions

Diagnostics of the parameters of the counter devices is carried out in a room measuring 6x10 m. Thus, the area is $S$ = 60 $m^2$. At a height $H$ = 3 m the volume of the room is $V$ = 180 $m^3$.

The works are carried out by five workers. So, per worker, there is 12 $m^2$ of space and 36 $m^3$ of room volume that satisfies the requirements of [29], according to which the volume of production premises per worker should be at least 15 $m^3$, and the area should be at least 4.5 $m^2$.

The enterprise operates in one shift. The working day lasts 8 hours: from 9:00 AM to 6:00 PM. There is a lunch break from 1:00 PM to 2:00 PM.

The PC room has natural and artificial lighting. Natural lighting – single-sided, penetrates through lateral light slits and provides a natural light intensity (NLI) of 1.5 %. The windows of the room are equipped with jalousie. Artificial lighting is made by fluorescent lamps, which provides the value of illumination on the surface of the desktop in the area of documents 200 lux. To create such a level of illumination, lamps of the type LB with a power of 40 W, light output of 70 lm/W are used.

There are three computers and computer peripherals in the operators' room. Computers are integrated into the local network. The main equipment consists of: 5 system units of mini ATX type; 5 monitors ASUS VH197DR; A4 printer HP LaserJet P2055dn; A3 printer HP Color LaserJet Pro CP5225.

The room has one entrance. The equipment is located in such a way as to ensure easy access to all workplaces. The surface of the floor is even, without potholes, it is not slippery, convenient for dry and wet cleaning. Two powder fire extinguishers of OP-1 type are installed in the room. The room is equipped with fire prevention system IPD-3.4. The detector detects fire, accompanied by the appearance of smoke, and produces sound and light alarms of a fire. The detector operates in standalone mode and is powered by a battery of type DURACELL MN1604 6LR61.

The desks of the workplaces on which the workers work have a height of 800 mm, a length of 1400 mm, a width of 800 mm, a seat height of 450 mm, a height for the legs - 650 mm, which ensures the convenience of the workplace. The height and design of the desktop is chosen so that it is easy to move from a seated working position to a standing position.

The monitor, in the workplace, is located at an optimum distance from the user's eyes, which is 600 mm. The location of the monitor should ensure the convenience of visual observation in a vertical plane at an angle of 30 degrees to the worker's normal line of view.

The keyboard is located on the table surface at a distance of 200 mm from the edge close to the user. The keyboard and the mouse are arranged so that they provide good visibility of the screen, convenience of manual control in the zone of reach of the monitor field. The placement of the printer in the workplace provides a good visibility of the video-display terminal, the convenience of manual control of the input/output device in the zone of reach of the monitor field in accordance with the requirements [30].

The room has an air conditioning system. Classification of air conditioning system: comfortable type, which is designed to create the most environmentally friendly air for humans; seasonal, carries out heating and humidification of air for a cold period, and for warm period – cooling and drying of air; local; direct current (processes only external air); low pressure; small capacity.

## 5.2 Analysis of harmful and dangerous factors

When working on a computer, the main load falls on all elements of the visual analyzer. This load can lead to visual impairment (partial loss of ability to perceive the magnitude, shape and color of objects, their mutual placement and the distance between them).

The activity of computer users is characterized by prolonged hours of work in a monotonous tense seated position, small motor activity with significant dynamic loads that fall only on the hands. This kind of work can lead to a series of painful symptoms, which are united by the common name - a syndrome of prolonged static load. This syndrome may manifest as fatigue, stiffness, pain, cramps, numbness.

While working on a computer, one should be afraid of a disease such as osteochondrosis and its complications (displacement of vertebrae, damage to the intervertebral joints, impaired posture, etc.). Computer users may experience skin disease in the form of a rash, itching, peeling, dermatitis.

When computers are used, sweating organs, the musculo-skeletal system, reproductive function, and the central nervous system are also at risk. In addition, computer users are affected by a whole range of factors of low intensity, the negative effect of which is developing gradually and secretly. Therefore, diseases manifest themselves only after many months or even years of work, when it is already extremely difficult to treat them.

Factors affecting the functional state of computer users are as follows:

1. Thermal radiation - electromagnetic radiation with a solid spectrum produced by heated bodies due to their internal energy.
2. The ionic composition of the air affects the development of fatigue, cardiovascular system, broncho-pulmonary apparatus, hematopoiesis, nervous system, short-term memory.
3. The electric voltage reflects the magnitude of the difference in the electroscopic forces on one and the other side of the surface of collision of two disparate bodies.
4. Visual work with the monitor has a major impact on the PC user, and visual discomfort is manifested even with the use of liquid crystal displays.
5. Prolonged static load syndrome.

6. Electromagnetic field. It acts on the cardiovascular system, increases fatigue, irritation, and eye fatigue. The electromagnetic field created by computer systems has a complex spectral composition in the frequency range from 0 Hz to 1000 MHz. The electromagnetic spectrum emitted by the monitor is 50 Hz and consists of X-ray, optical and radio frequency bands. Sources of electromagnetic radiation when working on a PC are:
   - Monitor (50 Hz);
   - Frame scan and synchronization unit (48 - 160 kHz);
   - Linear scan and synchronization unit (15 - 110 kHz);
   - System unit (50 Hz - 1000 MHz);
   - Input/output devices (0 - 50 Hz);
   - Uninterruptible power supply (50 Hz, 20 - 100 kHz).
7. The electrostatic charge does not carry a large amount of energy, but the high potential difference contributes to the formation of currents sufficient for instantaneous heating and failure of sensitive electronic components or to damage their crystal lattice, which in turn leads to a change in the properties and parameters of the chips. Electrostatic charge can lead to the following problems: failure of electronic components; attraction or repulsion of charged objects; inflammation; damage to the imprint; electric shock to the operational personnel.
8. Visual parameters, i.e., screen resolution, font, etc.
9. The nature of the labor process.
10. Socio-psychological issues.

### 5.3 Occupational safety measures

Every day, before starting work, the screen of the video terminal shall be cleaned from dust and other contaminants.

When working on a computer, it is necessary to observe the modes of work and rest.

After the end of the work, the video terminal and computer shall be disconnected from the power supply network.

In the event of an emergency, you must immediately disconnect the video terminal and computer from the power supply network.

In world practice, the prevention of damage to the health status of the video-display terminal users with the help of technical means is carried out mainly in the following areas:

*Monitors improvement.* The display cases became shielded (a metal layer several microns thick is sprayed onto the case). As a result of the application of this technology, the electric and electrostatic fields have been significantly reduced and it managed to provide maximum safety for the user. There were also "smart" displays, which automatically change the brightness on the screen, depending on the change in external lighting.

Important ergonomic characteristics are constantly improved, in many respects they determine both other technical characteristics and convenience of working with the monitor: screen size, screen mask type, screen coverage, radiation and power consumption, curvature radius of the screen, monitor and screen angle, weight and size, optical characteristics of the screen, monitor frequency (horizontal and vertical scan frequency), monitor functional characteristics (body design and stands, way to connect the monitor to the computer).

Comparatively recently, the *electromagnetic radiation neutralizer* appeared in the Ukrainian market, which, due to the phenomenon of interference, substantially (more than 80%) reduces the intensity of external electromagnetic radiation.

Scientists of the National Technical University developed a protective device "Forpost – 1", which creates an obstacle between the user and the radiation source.

*Computer glasses*, on the lenses of which a special composition is sprayed, which plays the role of light filters, bringing the color characteristics of monitors to the spectral sensitivity of the human eye.

*Protective screens (filters),* the main functions of which is to protect the PC user from electromagnetic radiation, reduce eye fatigue, and increase the comfort of work.

*Exercise for the eyes* every 20-25 minutes of work on a PC.

*Physical exercises* for elimination of local fatigue.

Personal protective equipment:

1. Computer glasses: when using them, the screen brightness is reduced to an acceptable level, the image contrast improves (due to absorption of the blue-light blue part of the spectrum), the protective layer absorbs the ultraviolet radiation harmful to the retina, drowsiness decreases (due to absorption of the yellow spectrum), visual acuity increases by increasing the red-orange part of the spectrum), the ability to see different colors increases (due to the transmission of light in the green part of the spectrum).

2. Protective screens (filters): protect the PC user from electromagnetic radiation, reduce the load on the eyes, and improves the comfort of work.

The main protective measure that ensures the safety of persons working on a PC from static electricity is protective grounding.

## 5.4 Calculation of artificial lighting

Lighting in the working room is 200 lux. According to normative documents it should be not less than 400 lux. In order the illumination meets the standards on the working surface, we shall install a lamp. Let us calculate the parameters of the lamp so that the illumination meets the standards.

Since the reflecting ability of the working room is small, then the calculation will be done according to the point method.

For point sources, the luminous flux of a separate lamp is:

$$\Phi = \frac{1000 E_{\min} K_3}{\mu \sum_{i=1}^{n} e_i},$$

where $E_{min}$ - minimum illumination;

$K_r$ - reserve ratio;

$\sum_{i=1}^{n} e_i$ - amount of conditional illumination;

$n$ - number of recorded lights;

$\mu$ - coefficient of additional illumination.

Let us calculate the luminous flux:

$$\Phi = \frac{1000 \cdot 400 \cdot 1,25}{1,2 \cdot 200} = 2083,333 \,\text{lm}$$

In order to provide the necessary luminous flux, we shall install a lighting fixture with a lamp 4U – 35 having the following characteristics: light base E27; temperature 4200 K; power consumption 35 W; luminous flux 2100 lm.

**5.5 Emergency analysis**

Emergencies during the PC operation include cases where a person may be exposed to electric shock and a fire in the working room. Let us consider the workers' actions in the event of such situations.

The workers' actions in case of electric shock:

- urgently release the person affected with electric current (through the outage of power in the room, general power supply at the switchboard or in any other way);
- call emergency medical assistance (103);
- provide the first medical aid to the affected person, taking into account the following:
  a) if the affected person is unconscious, but breathes, it is necessary to put him/her equally and comfortably, to unbutton the clothes, to create an inflow of fresh air and to provide complete rest;
  b) if there are no vital signs before the arrival of doctors, artificial respiration should be given to the affected person.

The workers' actions in case of fire:

- calling 101 immediately report to the fire brigade about the occurrence of fire in the premises, at the same time, it is necessary to specify the address, the number of floors of the building, the place of fire occurrence, the situation on the fire, the presence of people, as well as your last name;
- take (if possible) measures to evacuate people, extinguish (localize) fires with the use of primary means of fire extinguishing and to preserve material assets;
- report to the head (deputy heads) or a responsible competent official and the guard in charge on the fire occurrence;
- if necessary, call other emergency services (medical, gas safety service, etc.).

## CONCLUSIONS

As a result of the research, it was found that at the enterprise there is no universal method for electricity consumption data recovery, which in all cases yields a result with minimal error. When recovering lost data, it is necessary to analyze the type of function.

If in the function, there are gaps of the first kind, local methods should be used to recover it. When using local methods, the function must be divided into separate segments between which there is a gap and the obtained samples must be examined separately. Otherwise, if one dependence is found for the entire interval, there is an additional error in the gap points of the function. Subsequently, dependences were found for segments that reflect the consumption of electricity and natural gas. In this case, the relative error of these results in comparison with the initial data does not exceed ± 5%.

If the studied function on the whole segment has no obvious gaps and is relatively uniform, then it is advisable to apply global data recovery methods for it.

The construction of dependences is verified by all the global methods of the software Matlab with the library of graphic models Curve Fitting Toolbox.

Three dependences were considered for recovery of data on electricity consumption:

- the used power on the produced ammonia;
- the used power on natural gas consumption.
- consumption of natural gas on the produced ammonia.

For each function, dependencies and relative errors were found. Since functions are different in nature, data recovery models with the smallest relative error are different for them. For the dependence of the used power on the produced ammonia, the Fourier method has the smallest relative error, depending on the consumption of natural gas on the produced ammonia – the Sum of Sin Function method, for the dependence of the used power on natural gas consumption – the Rational method.

For a comprehensive evaluation of the results obtained, relative errors should be considered as a circular diagram divided into sectors. In each sector, the relative errors of the methods are constructed for a specific dependence. Vectors from each sector are interconnected, forming triangles. A triangle with a minimum area determines the types of methods with minimum values of relative errors. In practice, it is advisable to compare figures with a minimum area and formed from vectors of one method. In this case, with a slight difference, in order to simplify mathematical calculations, one method should be used to identify the relationships between all the constituents.

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